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PUBLICATIONS

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Earthquake Investigation Committee

IN

FOREIGN LANGUAGES.

No. 23

Report on the Great Indian Earthquake of 1905.
Part I: Seismograms.

TOKYO, 1907.

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PREFACE.

Immediately after the disastrous earthquake of April 4, 1905, the author proceeded to India, by order of the Imperial Government, to study the seismic phenomena, arriving at Simla on May 30, and spending 2½ months in visiting different places in the shaken area.

The present Number of the *Publications*, constituting Part I of the Report on the Indian Earthquake, contains a collection of the more typical seismograms obtained at various seismological stations, on the occasion of the catastrophe, which caused a loss of 20,000 human lives. For the sake of convenience of printing, the descriptions of the different seismograms, and the discussions of the transit velocities, vibration periods, etc., are given, as Part II of the Report, in No. 24 of the *Publications;* the first two parts together giving the results of the seismographic observations of the great disturbance in question. Part III contains a general account of the earthquake.

One of the objects in issuing Parts I and II of the Report is to prepare a systematized account of the instrumental observations of the great earthquake, which I have specially studied, to be laid, for discussion, before the learned members of the General Conference of the International Seismological Association to be held in September next at the Hague. I am aware that in this attempt I have fulfilled my task by no means satisfactorily, and will consider myself highly successful if the results of my analysis prove of use to seismologists for the researches on the physics of the earth's crust.

F. Omori.

March, 1907. Seismological Institute, Tokyo.

REPORT ON THE GREAT INDIAN EARTHQUAKE OF 1905.

PART I: SEISMOGRAMS.

By

F. OMORI, Sc.D.,

Member of the Imperial Earthquake Investigation Committee.

1. ***Introductory.*** The earthquake of April 4, 1905, in the north-western part of India, was a very large disturbance, and caused a loss of human lives, whose number was surpassed by no other destructive seismic shock in the modern times. This catastrophe, generally known as the Kangra Earthquake, and the great Assam and Bengal earthquake of June 12, 1897, were probably caused by the stress in the earth-crust which is connected with the curvilinear form of the Himalayas. As India is visited by severe earthquakes from time to time, it is to be greatly desired that precautions should be taken in the construction of houses so as to mitigate the seismic damage to life and property.

The misfortune which had befallen the people of British India deeply touched the Japanese. On receipt of the news of the catastrophe His Imperial Japanese Majesty at once sent a message of sympathy to His Britannic Majesty. The mayor of Tokyo also dispatched a telegram of condolence to King Edward, while the War Minister addressed to the Viceroy of India a telegraphic message expressing his deep sympathy and sorrow for the fatal calamity that had befallen Indian soldiers at Dharmsala. The *Jiji-Shinpo*, a leading daily newspaper, editorially commented on the seismic disaster and at once opened a subscription for the benefit of the victims of the earthquake.

2. *Note on the Character of Earthquake Motion.* The earthquake motion, especially that due to a great disturbance, is by no means simple in character, but consists of different sets of vibrations, whose period varies between a fraction of a second to over 1 minute. The quickest tremors, which I have ever observed, was in the case of one of the after-shocks of the great Mino-Owari (Japan) earthquake of Oct. 28, 1891, registered at the temporary seismological observatory set up in the village of Midori in the Néo-Valley, the most central part of the meizoseismal zone, its complete period being only 0.023 sec. On the other hand, the longest period of vibration, which I have so far observed, was 86 sec. and occurred in the EW component diagram of the Kangra Earthquake obtained at Tokyo. It is quite probable that, in the case of a great seismic disturbance, there exist still slower vibrations, of period, say, of several minutes, or of even over 1 hour; the different seismographs in use at present recording only the quicker components of the earthquake motion.

The periods of vibration at a given place seem in the case of the *macro* or *sensible* earthquake motion to remain nearly constant for different earthquakes;* the same conclusion also being probably true of the *micro* or *insensible* earthquake motion of pulsatory nature, or that consisting of slow-period vibrations.†

Further, for the latter case, the principal periods seem to remain essentially the same for different places all over the earth. These facts would seem to point out that the whole earth's crust is making slow small vibrations with definite periods, whose amplitudes become enlarged at the time of a great earthquake shock, just as the waters of a given portion of a sea are thrown, by great sub-marine earthquakes and volcanic eruptions, or by atmospheric depressions, into destructive tidal disturbances, whose periods are the same as those of the waves existing at ordinary times and are constant at each given sea-coast. Slow vibrations generally appear in earthquakes which are sufficiently great, and the supposition held by some seismologists that long-period movements are to be observed only at a great distance from the seismic centre is evidently untrue; slow vibrations of period over 30 or 60 sec. having been observed in Tokyo on the occasion of some earthquakes, which originated off the southern and eastern coasts of Japan. The fact is probably that the different sets of slow and quick movements are generated simultaneously at the earthquake centre, but the vibrations of shorter periods are, in their radial propagation, reduced in amplitude much more quickly than those of slower periods, due to the viscosity of the material forming the earth's crust; the result being that the vibrations of the macroseismic nature exist only slightly in the earthquake motion due to a distant source, while the movements of different slow periods become successively prominent at the varying radial distances.*

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* The *Publications*, No. 11.

† The *Publications*, Nos. 5 and 13, also the *Bulletin*, Vol. I, No. 2.

3. ***Teleseismic Motion and Instrumental Record.*** From what has been said in the preceding §, it will be readily understood that, in the teleseismic disturbance due to a large source, slow vibrations play an important part; the division of the motion into the different phases or sections depending, in the first place, on the amplitude of the constituent vibrations. From this point of view, a standard seismograph must be one of long period.

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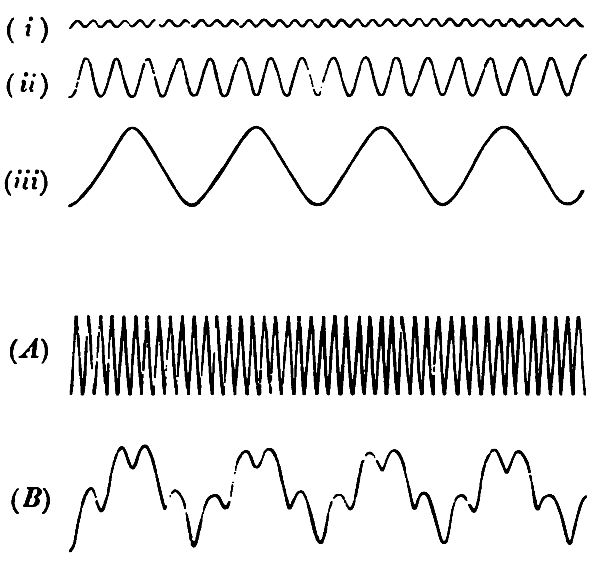
* The *Publications*, No. 21, p. 80.

As the intensity, or maximum acceleration, of the earthquake motion is proportional to the amplitude, but varies in the ratio of the inverse square of the period, the friction at the junction of the "steady axis" of a mechanically registering seismograph and the recording pointer, and that between the latter and the record-receiving surface, will interfere very much with the accuracy of the result. For example, a vibration of 40 seconds period will be affected by the friction 100 times more than another of equal size, whose period is 4 sec. Further, to correctly record a vibration the natural oscillation period of the "steady mass" must be much longer than that of the latter. Hence the real range (double amplitude) of motion of a very slow period, say, of over 40 seconds, would be always larger than indicated on the record furnished even by long-period seismographs in use at present; the consequence beingt hat the records from different seismographs differ considerably from each other, according, amongst others, to the proper oscillation period of the latter. Thus, let the earthquake motion be composed, for simplicity's sake, of three sets of vibrations, (*i*), (*ii*), and (*iii*) whose periods are, for example, 4, 8, and 32 seconds, respectively. If, now, the



natural oscillation period of a seismograph be short, say, not more than 4 seconds or so,and if the multiplication ratio of the recording pointer be large, the seismogram would simply consist in large pendulum oscillations as is diagrammatically represented in (A) slower movements of (*ii*) and (*iii*) types being not indicated at all. On the other hand, if the natural pendulum period be sufficiently long, the record will be as is represented in (B), the different sets of vibrations being represented more nearly in their true sizes. In this latter case, however, small quick vibrations of the (*i*) type will be almost entirely obscured, due to the superposition of large slow movements.

4. *Function of Microseismographs.* No single seismogragh can record clearly all the different sets of the vibrations composing the earthquake motion, when the slow component is of a large amplitude. At least two instruments are required for the complete observation of the horizontal (or vertical) motion: the one, with a long oscillation period of 60 sec. or more, recording the slower component, and the other, with a short period of some 15 seconds, recording the quicker component.

To prolong the oscillation period of a horizontal pendulum, the following three conditions are necessary :—

(1). The weight of the heavy bob must not be too great, as the point of support must always be kept very sharp.

(2). The length of the strut, or the horizontal distance between the point of support and the steady axis, must not be short.

(3). The height of the pendulum, or the vertical distance between the point of support and the point of suspension, must be made large.

With a horizontal pendulum set up in the " Earthquake-proof

House," which is 2.65 meters in height and whose strut was 1 meter in length, the oscillation period was raised to 3 minutes, the weight of the bob being 7½ kg.* By increasing the height and the length in question the oscillation period can of course be more lengthened.

For the observation of the W_2 wave, or the earthquake motion propagated along the major arc between the centre of disturbance and a given station, and the W_3 wave, namely, the repetition of that first propagated along the minor arc, or the shortest path, the friction of the instrument must be made very small, the oscillation period being made suitably long.

5. ***Seismoscope.*** Although the primary object of Seismometry is to record correctly or absolutely the earthquake motion, sensitive seismoscopes are also invaluable in the researches on earthquake phenomena, especially, in observing, (*i*), the small movements at the commencement of the 1st preliminary tremor, and, (*ii*), the feeble vibrations of the W_2 and W_3 waves. The instruments best adapted to these two last mentioned purposes would be, respectively, a horizotal pendulum of very small mass and of a high magnification, with an oscillation period of 3 or 4 seconds, and a similar one with an oscillation period of about 20 sec.; the registration being in each case made photographically. Instruments of Professor Milne's type, with proper improvements, would, in this respect, prove very useful.

For the observation with such seismoscopes as above supposed there is no need for damping the motion of the pendulum, the object being to utilize the proper oscillations of the latter. A high magnification instrument with a large amount of friction fails to record satisfactorily the slow small vibrations.

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* The *Publications*, No. 5; subsequently the weight of the bob was increased to 46 kg.

6. *Observations of the Kangra Earthquake.* In response to my circular asking for the copy of the seismographic or magnetographic records of the Kangra Earthquake, photographic or printd reproductions of the diagrams have been sent in from the following stations :—

Japan	Mizusawa, Ōsaka, Kōbe, Tadotsu, Kyōto, Ishinomaki, Miyako.
Formosa	Taihoku, Taichu, Tainan.
India	Dehra Dun, Barrackpore, Colaba(Bombay), Calcutta (Alipore), Kodaikanal (Madras).
China	Shanghai (Zikawei).
Philippines	Manila.
Java	Batavia.
Austria-Hungary	Laibach, Pola, Triest, O'Gyalla.
Italy	Ximeniano, Querce,and Quarto-Castello (Florence), Ischia, Rocca di papa, Padova.
Germany	Potsdam, Strassburg, Göttingen, Leipzig.
Sweden	Upsala.
Great Britain	Shide, Kew, Liverpool (Bidston), Birmingham, Edinburgh, Paisley.
Spain	San Fernando.
Mauritius.	
Cape of Good Hope.	
Canada	Toronto, Victoria, B.C.
The United States	Baltimore, Washington, D. C., Cheltenham.
Mexico	Tacubaya.
Brazil	Rio de Janeiro.
New Zealand	Christchurch, Wellington.

I have here to express my warmest thanks to the seismologists in charge of these observatories for having so kindly supplied me with the results of their observations.

Besides the places above mentioned, in Tokyo the earthquake was observed at three stations, namely, the Seismological Institute (at Hongō), the branch Observatory of Hitotsubashi, and the Central Meteorological Observatory.

The diagrams obtained at the different seismological observatories have furnished very valuable materials of investigation, each showing, according to the nature of the instrument, its own characteristics. What is specially interesting of these seismograms is that the latter indicate very distinctly the W_2 motion, or the earthquake propagated along the major arc. This motion was in many cases quite large, obscuring by its superposition the W_3 wave, or the repetition of the earthquake proper.

Further, in the discussion of the propagation velocities and the duration of the 1st preliminary tremor, I was enabled to utilize the published results of seismographic observations at the following stations :—

Russian Turkestan	Taschkent.
Siberia	Irkutsk.
Caucasus (*Russia*)	Tiflis, Achalkalaki, Batum, Borshom, Derbent, Schemacha.
Russia	Jurjew ; Nikolajew.
Samoa	Apia.
Porto Rico	Vieques.
Hawaii	Honolulu.
Syria	Bairut.
Azores	Ponta Delgada.
Servia	Belgrade.
Austro-Hungary	Krakau,

Germany .... Jena, Hamburg.

Italy .... Messina.

The number of the stations taken into account was nearly 70, while that of the diagrams I have analyzed was also nearly 70.

7. *List of Seismograms.* Pls. I to XXII contain 41 more typical seismograms, all reproduced in the original size, except the Quarto-Castello register which has been reduced half size. The following is a list of the different seismograms.

LIST OF FIGURES (PLS. I TO XXII).

SEISMOGRAPHIC RECORDS OF THE GREAT INDIAN EARTHQUAKE OF APRIL 4, 1905.

PLS. I TO VIII. JAPANESE STATIONS.

Pls. I to VI. Seismological Institute, Imperial University, Hongō, Tōkyo, Japan.

Time of Earthquake Commencement $=0^h\ 59^m\ 08^s$.

*Pl. I. Fig. 1. Omori Horizontal Pendulum. EW Component.** *Weight of the bob = 17.4 kg. Multiplication = 15. Pendulum Period = 61.5 sec.*

The letters *a, b, c, d*, ... ***A, B***, *C, D*, ... *X* denote the vibrations corresponding to those denoted by the same letters in the Ōsaka EW Component Seismogram (Pl. VI).

W_2' is the commencement of the vibrations propagated along the Major Arc, from India to Tokyo, probably corresponding to the approximate beginning of the 2nd phase of the principal portion. W_2 corresponds to some later epoch in the same phase.

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* By mistake, the arrow indicating the commencement of the earthquake has been marked about 17 sec. too early.

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TOKYO, 1907.

Pl. IX. Figs. 10 and 11. U.S. Coast and Geodetic Survey Magnetic Observatory of Cheltenham, Maryland, United States of America. Omori Horizontal Pendulum of portable form. Multiplication = 10. Time of EQ. Commencement = $1^h\ 08^m\ 39^s$.

Fig. 10.	*NS Component.*	*Pendulum Period*	*= 19 sec.*
Fig. 11.	*EW* „	„	*21* „ .

Fig. 12. U.S. Weather Bureau, Washington, D. C. Weather Bureau (Omori Type) Horizontal Pendulum. NS Component. Multiplication = 10. Pendulum Period = about 19sec.
Time of EQ. Commencement = $1^h\ 08^m\ 25^s$.

In Figs. 10, 11, and 12, the numerals, 1, 2, 3, 4, 5, 6, and 7, correspond respectively to the commencements of the 1st and 2nd preliminary tremors, and of the 1st to 5th phases of the principal portion. W_2 denotes the commencement of the Major Arc propagation of the earthquake motion.

Pl. X. Omori Horizontal Pendulums of portable form.

Figs. 13 and 14. Observatory of Tacubaya, Mexico.
Time of EQ. Commemcement = $1^h\ 11^m\ 25^s$.

Fig. 13.	*EW Component.*	*Pendulum Period*	*= 17.3 sec.*
Fig. 14.	*NS* „	„	*17.6* „ .

Fig. 15. Birmingham, England. (Dr. Davison.) *EW Component. Weight of the bob = 9 kg. Multiplication = 14.4 Pendulum Period = 34 sec.* Time of EQ. Commencement = $1^h\ 00^m\ 35^s$.

In Figs. 13, 14, and 15, the numerals, 1, 2, 3, 4, 5, 6, and 7, and the letter W_2 have the same significations as in Pl. IX.

Pl. XI. Fig. 16. Observatory of Quarto-Castello, Florence, Italy.
Time of EQ. Commencement = $0^h\ 58^m\ 47^s$.

(A). Grande Pendolo Orizzontale Stiattesi. Mass = 500 kg. NS Component. Multiplication = 25. Pendulum Period = 21.4 sec.

(*B*). *Grande Pendolo Orizzontale Stiattesi. Mass = 500kg. EW Component. Multiplication = 25. Pendulum Period = 17.4 sec.*

(*C*). *Grande Microsismografo Vicentini a pantografo. Mass = 500 kg. Multiplication = 40. Pendulum Period = 4.6 sec.*

The numerals, 1, 2, 3, 4, 5, and 6, have the same significations as in the 2 preceding Plates.

Pl. XII. Fig. 17. Royal Geodynamic Observatory of Ischia, Italy.

Time of EQ. Commencement = 0^h 58^m 56^s.

(*A*). *Porto d'Ischia. Pendoli Orizzontali Grablovitz.* (*Improved form*) *Multiplication = 8. Pendulum Period = 13.0 sec.* (*NS*); *17.0 sec.* (*EW*).

(*B*). *Grande Sentinella* (*Casamicciola*). *Pendoli Orizzontali Grablovitz.* (*Primitive form*). *Multiplication = 8. Pendulum Period = 11.3 sec.* (*NS*); *11.0 sec.* (*EW*).

(*C*). *Porto d'Ischia. Vasca Sismica. Multiplication = 70.*

(*D*). *Grande Sentinella* (*Casamicciola*). *Vasca Sismica. Multiplication = 90.*

Pl. XIII. Fig. 18. Royal Geodynamic Observatory of Rocca di papa (*Rome*), *Italy. Microsismografo Agamennone. Mass = 500 kg. Multiplication = 70. Pendulum Period = 4.2 sec. NW-SE and NE-SW Components.*

Time of EQ. Comemcement = 0^h 58^m 51^s.

Fig. 19. Philippine Weather Bureau, Manila. Vicentini Microseismograph. Weight of the bob = 100 kg. Pendulum Period = 2.4 sec. NNW-SSE Component.

Time of EQ. Commencement = 0^h 58^m 25^s.

Pl. XIV. Figs. 21 and 22. Royal Geological Survey Office, Leipzig, Germany. Wiechert's Astatic Pendulum. Weight of the *bob = 1100kg. Indicator-Multiplication = 250. Pendulum Period = 9.2 sec.*

Fig. 21. EW Component.
Fig. 22. NS „

Time of EQ. Commencement = 0^h 58^m 44^s.

Fig. 20. Government Observatory, Colaba, Bombay, India. Colaba Seismograph. NS Component. Pendulum Period = 27 sec.

Pl. XV A and Pl. XV B. Geophysical Institute, Göttingen, Germany Wiechert's Astatic Horizontal Pendulum. Weight of the bob = 1200 kg. Indicator-Multiplication = 160.

Fig. 23. NS Component. Pendulum Period = 15.7 sec.
Fig. 24. EW „ „ „ 15.3 „.

Time of EQ. Commencement = 0^h 58^m 55^s.

The original complete diagram has, for the convenience of printing been cut into two halves, so that Pl. XV A is continued to Pl. XV B.

Pl. XVI and Pl. XVII. Meteorological Institute, Royal University, Upsala, Sweden. Wiechert's Astatic Pendulum. Weight of the bob = 1000 kg. Indicator-Multiplication = 235. Pendulum Period = about 9 sec.

Fig. 25. NS Component.
Fig. 26. EW „

Time of EQ. Commencement = 0^h 58^m 22^s.

Pls. XVIII to XXII. Milne Horizontal Pendulum Seismograms.

The Milne Horizontal Pendulums are generally go located that the boom points N-S, recording the EW Component motion.

PLS. XVIII-XIX. BRITISH AND SPANISH STATIONS.

Pl. XVIII. Fig. 27. National Physical Laboratory, Kew Observatory, England.

Time of EQ. Commencement = $1^h\ 00^m\ 12^s$.

Fig. 28. Royal Observatory, Edinburgh, Scotland.

Time of EQ. Commencement = $1^h\ 00^m\ 00^s$.

The letters, *a, b, c, d, e, f, g, h, i, j, k, l,* denote the different maximum movements which can be well identified in the Kew and San Fernando Seismograms.

Fig. 29. Shide, Newport, Isle of Wight. C-Instrument, EW Component.

Fig. 30. Shide, Newport, Isle of Wight. B-Instrument, NS Component.

Time of EQ. Commencement = $1^h\ 01^m\ 00^s$.

The letters, *a, b, c, d, e, f, g,* in Figs, 29 and 30 denote corresponding movements in the two components.

Pl. XIX. Fig. 31. Liverpool Observatory, Bidston, England.

Time of EQ. Commencement = $1^h\ 00^m\ 36^s$.

Fig. 32. The Coats Observatory, Paisley, Scotland.

Time of EQ. Commencement = $1^h\ 00^m\ 00^s$.

Fig. 33. Marine Observatory of San Fernando, Spain.

Time of EQ. Commencement = $1^h\ 02^m\ 30^s$.

The letters, *a, a′, b, b′, c,......o,* denote the different maximum movements, most of which can be identified in the seismograms obtained at the British Stations, especially, at Kew and Edinburgh. In Figs, 27 to 33, W_2 denote the earthquake motion propagated along the major arc; the variation in the time of its commencement at the different stations being partly due to some dissimilarity of the pendulum periods, and partly to the difference in the epicentral distances,

Pl. XX. INDIAN STATIONS.

Fig. 34. Meteorological Observatory of Alipore, Calcutta.

Time of EQ. Commencement$=0^{h}\ 52^{m}\ 00^{s}$.

Fig. 35. Government Observatory, Colaba, Bombay.

Time of EQ. Commencement$=0^{h}\ 53^{m}\ 08^{s}$.

Fig. 36. Government Observatory, Colaba, Bombay.

The Float and Balance Records of the vertical motion.

Pl. XXI. NEW ZEALAND AND CAPE TOWN.

Fig. 37. Magnetic Observatory, Christchurch, New Zealand.

Time of EQ. Commencement$=1^{h}\ 10^{m}\ 00^{s}$.

Fig. 38. Wellington, New Zealand.

Time of EQ. Commencement$=1^{h}\ 09^{m}\ 48^{s}$.

The Wellington diagram has been cut into two, for the convenience of printing.

In Figs. 37 and 38, the corresponding movements are marked by the letters, *a*, *b*, *c*, *d*,...............*x*, *y*, *z*.

Fig. 39. Royal Observatory, Cape of Good Hope, South Africa

Time of EQ. Commencement$=1^{h}\ 02^{m}\ 30^{s}$.

Pl. XXII. CANADIAN STATIONS.

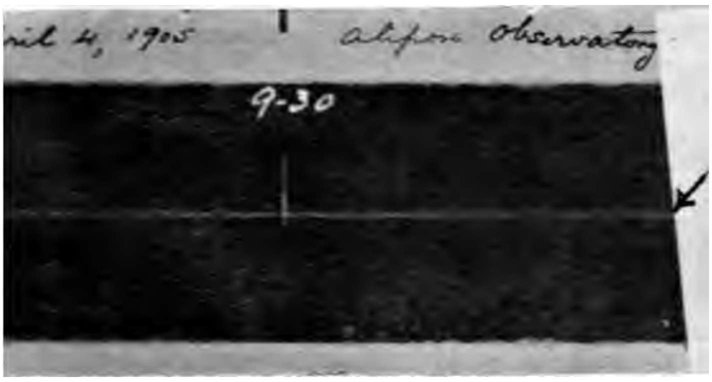
Fig. 40. Victoria, British Columbia.

Time of EQ. Commencement$=1^{h}\ 06^{m}\ 48^{s}$.

Fig. 41. Toronto Observatory, Ontario.

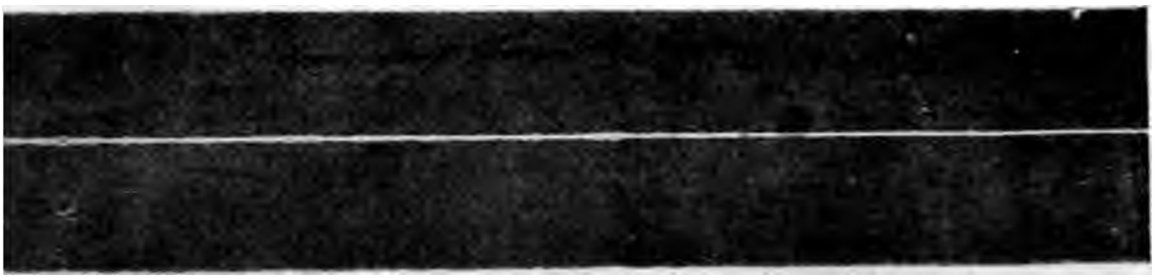
Time of EQ. Commencement$=1^{h}\ 06^{m}\ 36^{s}$.

V. Kuechler, Assistant Meteorological Reporter.



FIGS. 34 and 35.
MILNE HORIZONTAL PENDULUM RECORDS.

. BOMBAY. Director, N. A. F. Moos.



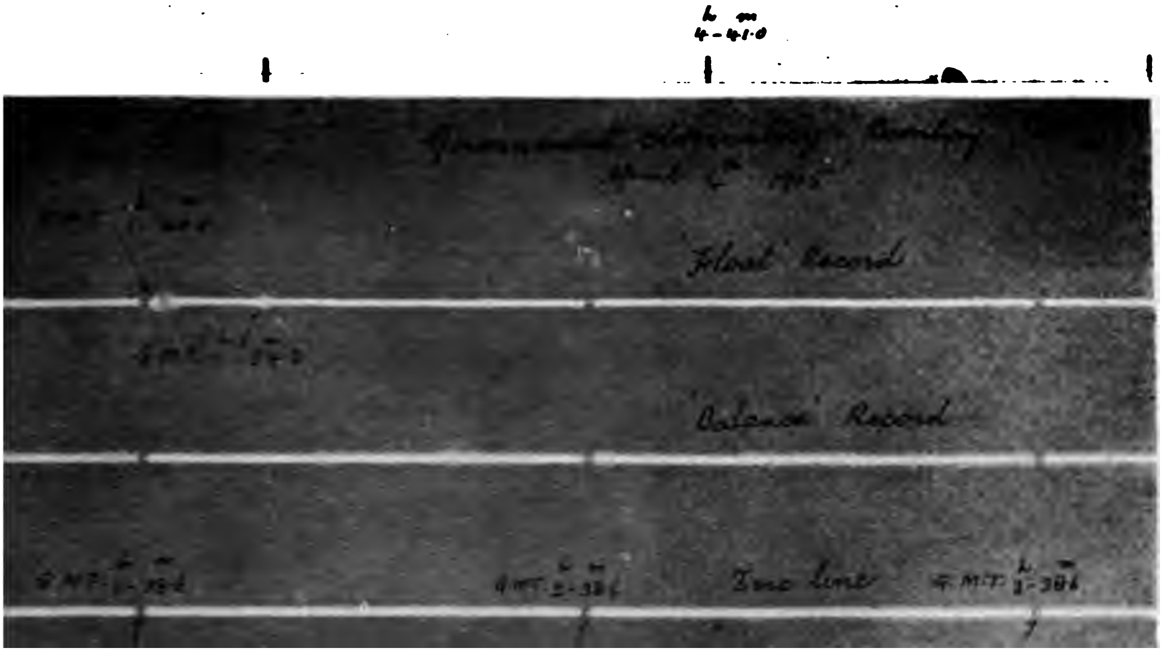


FIG. 34. ALIPORE OBSERVATORY, CALCUTTA.

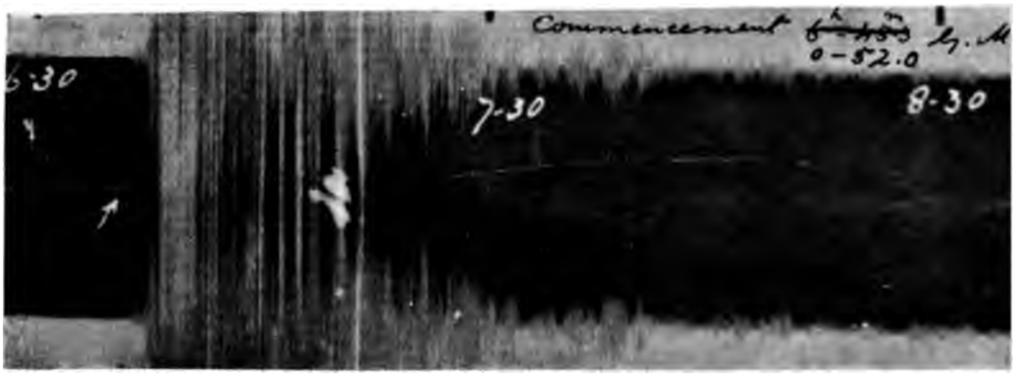
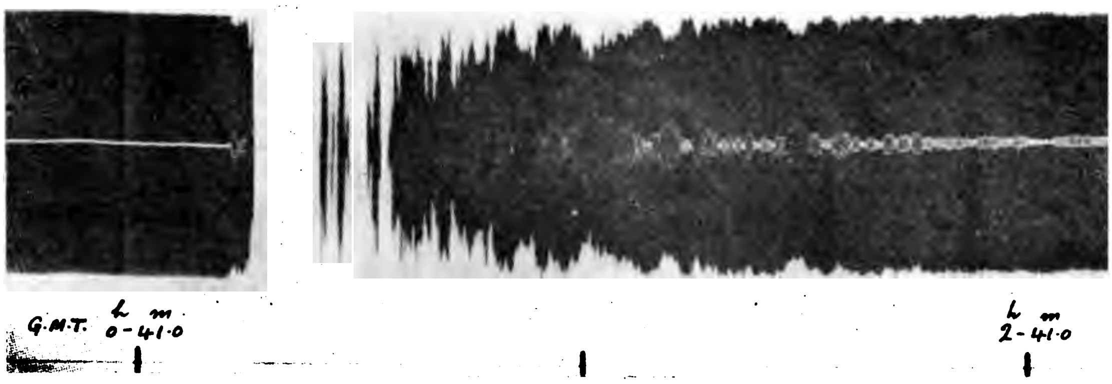


FIG. 35. GOVERNMENT OVSERVATORY, C



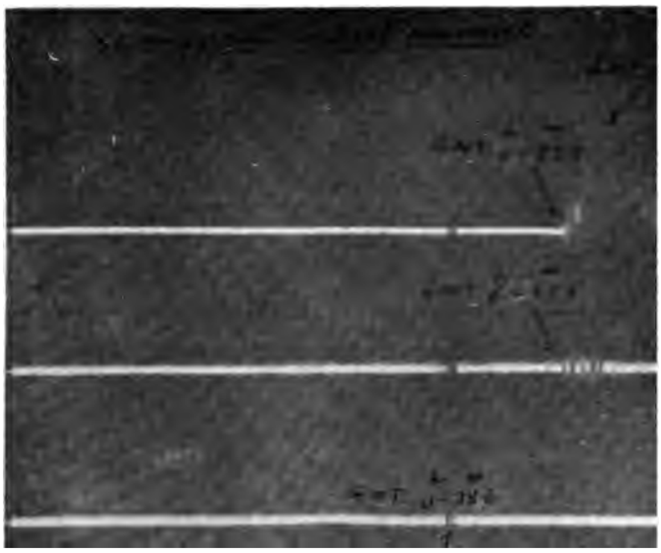
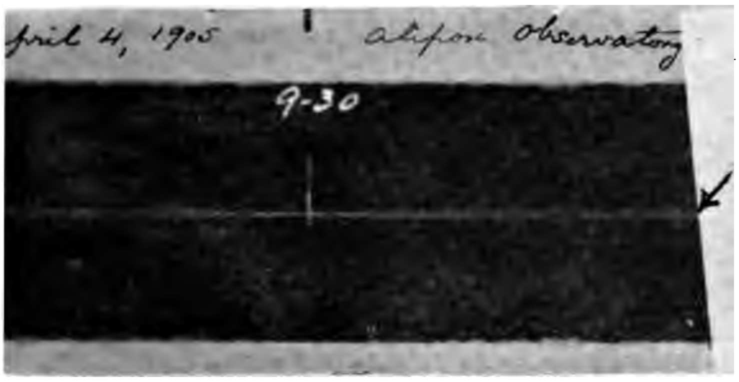


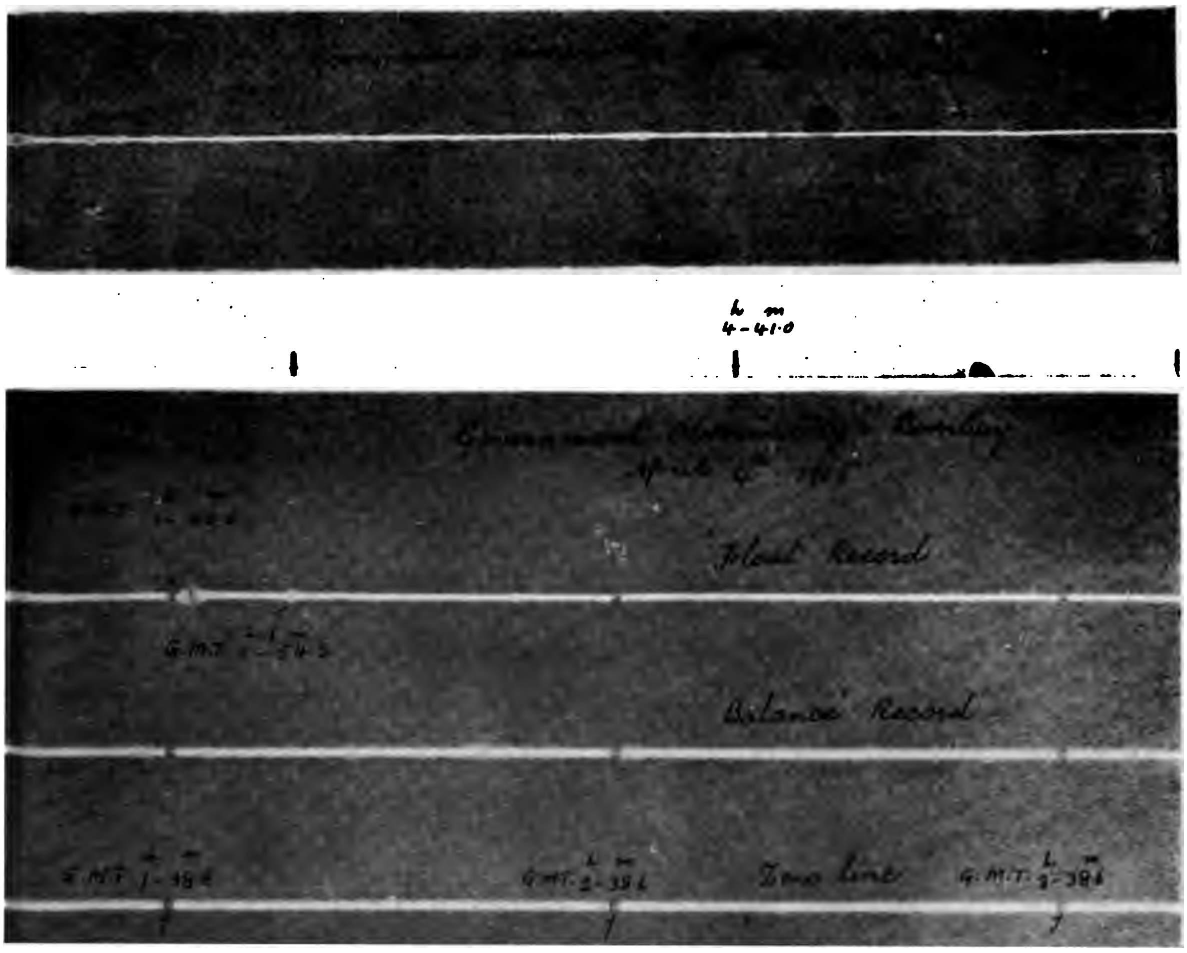
FIG. 36.
VERTICAL MOVEMENT
RECORDED AT COLABA,
BOMBAY.

W. Kuechler, Assistant Meteorological Reporter.



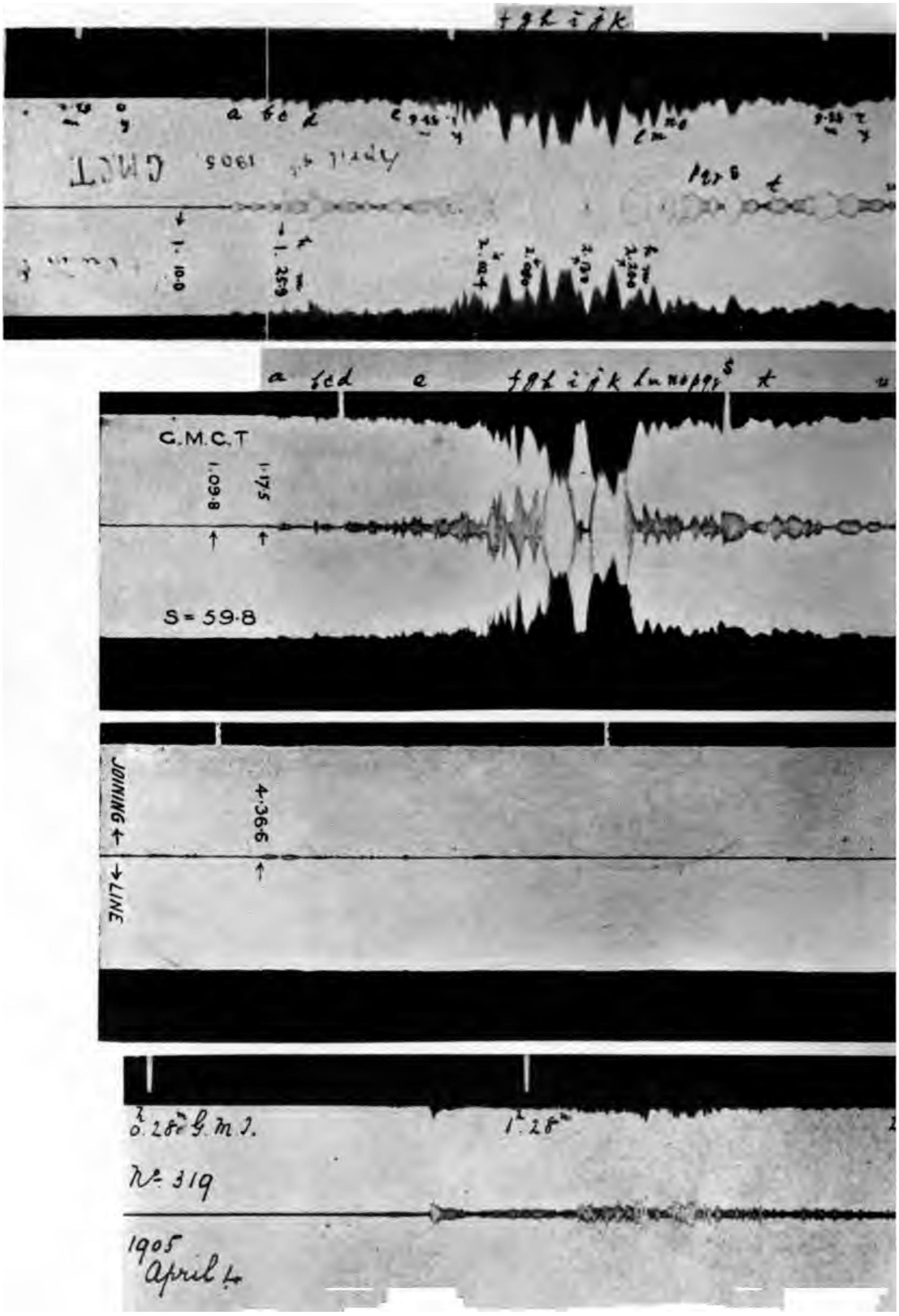
FIGS. 34 and 35.
MILNE HORIZONTAL
PENDULUM RECORDS.

A, BOMBAY. Director, N. A. F. Moos.

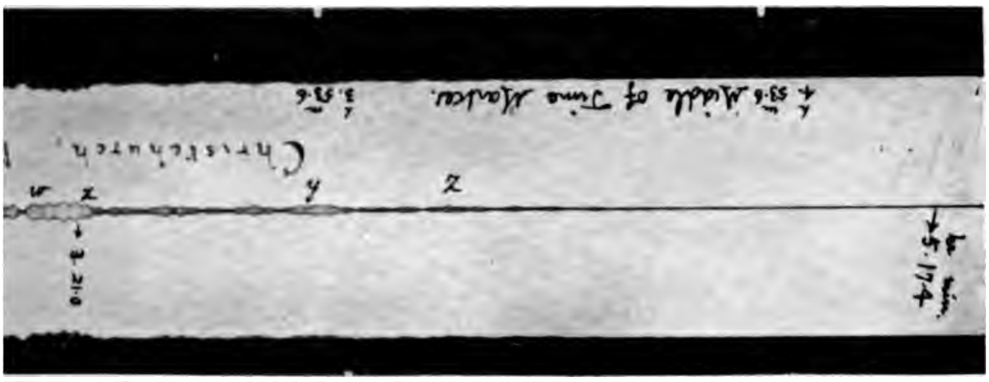


Milne Horizontal Pendulum Records of t

FIG. 37. MAGNETIC OBSERVATORY, CHRISTCHU



'H, NEW ZEALAND. Director, H. F. Skey, B. Sc.



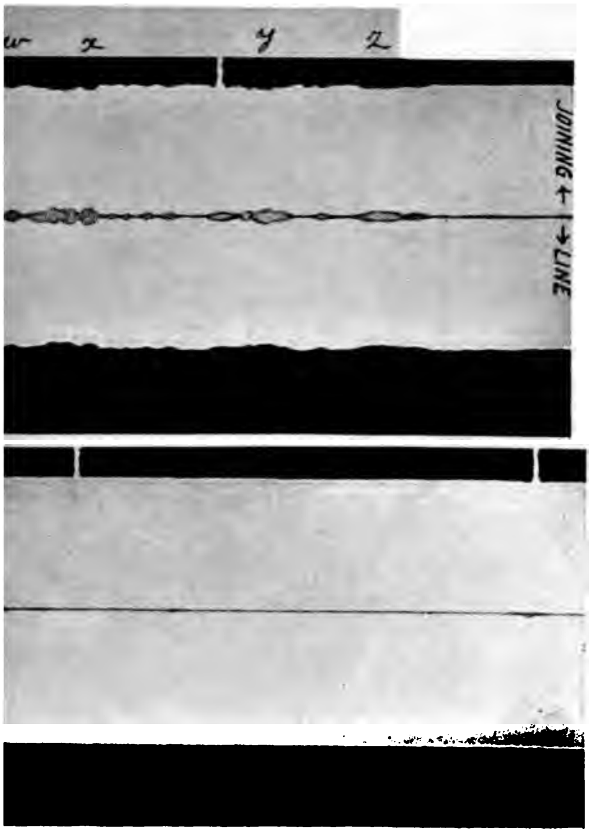


FIG. 38.
WELLINGTON,
NEW ZEALAND.
Director, George Hogben, M. A.

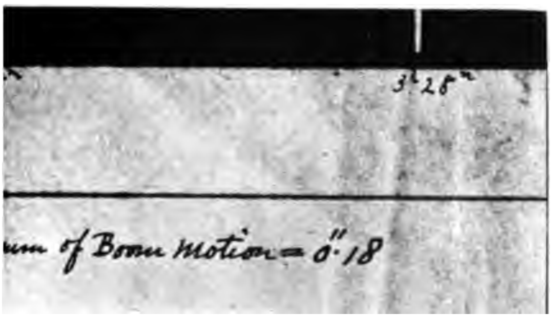


FIG. 39.
ROYAL OBSERVATORY,
CAPE OF GOOD HOPE,
SOUTH AFRICA.
Director, Sir David Gill.

Milne Horizontal Pendulum Records of

FIG. 40. VICTORIA, BRITISH COL

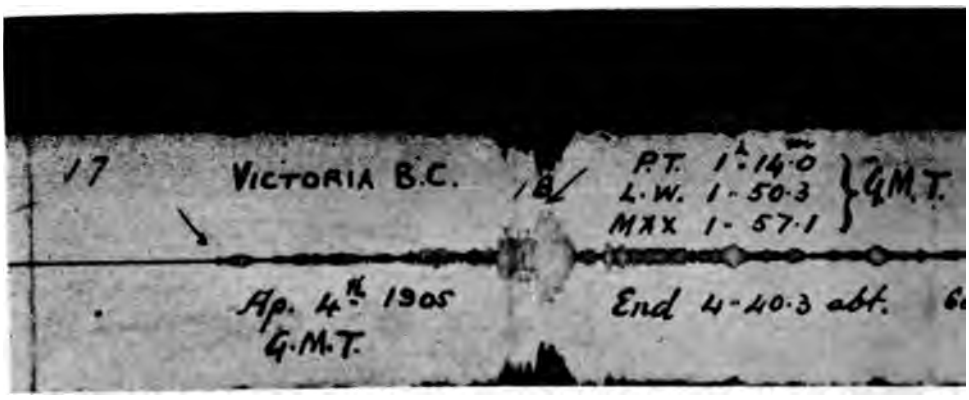
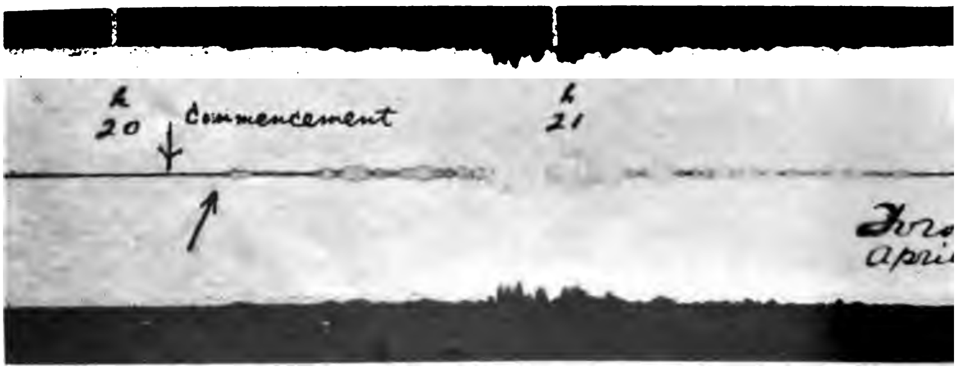
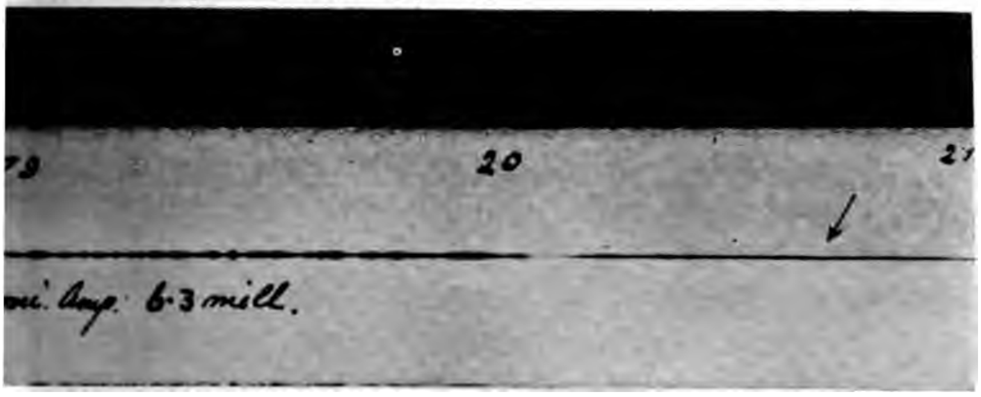


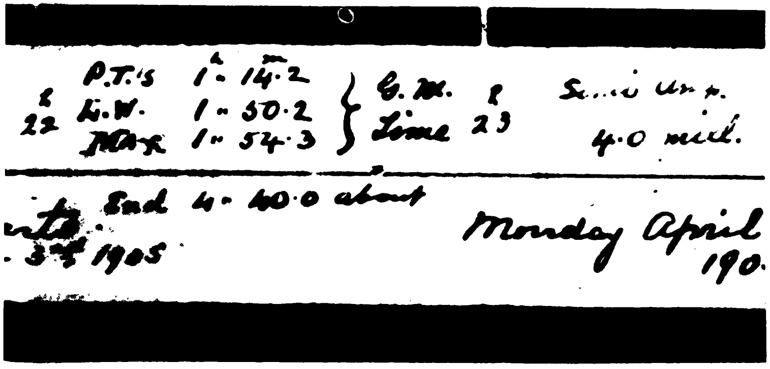
FIG. 41. TORONTO OBSERVATORY, ONTARIO



MBIA. Superintendent, E. Baynes Reid.



CANADA. Director, Professor R. F. Stupart.



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REPORT ON THE GREAT INDIAN EARTHQUAKE OF 1905.

PART II: SEISMOGRAPHICAL OBSERVATIONS.

By

F. OMORI, Sc.D.,
Member of the Imperial Earthquake Investigation Committee.

Chapter I. Introductory.

1. ***Himalayan Range and Seismic Activity.*** The topography of British India is highly characteristic, the great Himalayan range forming a very beautiful circular arc which extends in an east-west direction. (See Fig. 1.) As elsewhere stated, great earthquake regions often coincide with the steep convex, or outer, side of a curve formed by a mountain chain or a series of islands; the inner, or concave, side being only disturbed by occasional local shocks.* In the case of the Himalayan range, which rises abruptly from flat plains of India, the arcual form is probably due to a pressure from the Tibet side, which is still going on.

The large Indian seismic disturbance of April 4, 1905, usually known as the Kangra Earthquake, originated among the Sub-Himalayan chains in the Punjab (Fig. 1), and is to be regarded, together with the Assam and Bengal earthquake of June 12, 1897, as the result of the growth of the Himalayas. The latter form part of the great seismic zone extending from the Mediterranean on the west to Formosa on the east, along which no less than 11 large destructive earthquakes occurred within the 8 years between 1897 and 1905.*

---

* See the *Bulletin of the Imperial Earthquake Investigation Committee*, Vol. I, No. 2.

2. *Area of Sensible Motion.* The approximate boundary of the area, within which the motion of the Kangra earthquake was sensible, is shown by the line B in Fig. 1, its western, southern, and eastern limits being Quetta (Afganistan), Surat and False Point, and Lakhimpur (Assam), respectively. The extreme distance, at which the motion was felt, was about 1670 km, the areas enclosed within the three isoseismals corresponding to Nos. 10, 9, and 8, of the Rossi-Forel scale of seismic intensity being, according to Mr. C. S. Middlemiss, of the Indian Geological Survey, respectively 200, 1600, and 2150 square miles.†

The meizoseismal district, where serious damage was caused, and whose intensity of motion corresponded to the Nos. VIII, IX, and X, of the Rossi-Forel scale, stretched in an NW-SE direction, from the vicinity of Kangra and Dharmsala to that of Mussooree and Dehra Dun, over a distance of about 350 km (A, Fig. 1); the earthquake motion being much stronger on the north-western half, than on the south-eastern half, of the zone under consideration. It seems probable that the latter extends towards the north-west of Kangra and Dharmsala for some more distance.

3. *Intensity of Motion.* The intensity, or destructive power, of the earthquake motion may be represented by the maximum acceleration of the earth's particle in its vibratory movement‡; the approximate values of this quantity at some places in the strongly or violently shaken areas, deduced from the observations

---

* The *Bulletin*, Vol. I, Nos. 1 and 2.

† C. S. Middlemiss: "Preliminary Account of the Kangra Earthquake of the 4th April 1905." Records of the Geological Survey of India, Vol. XXXII.

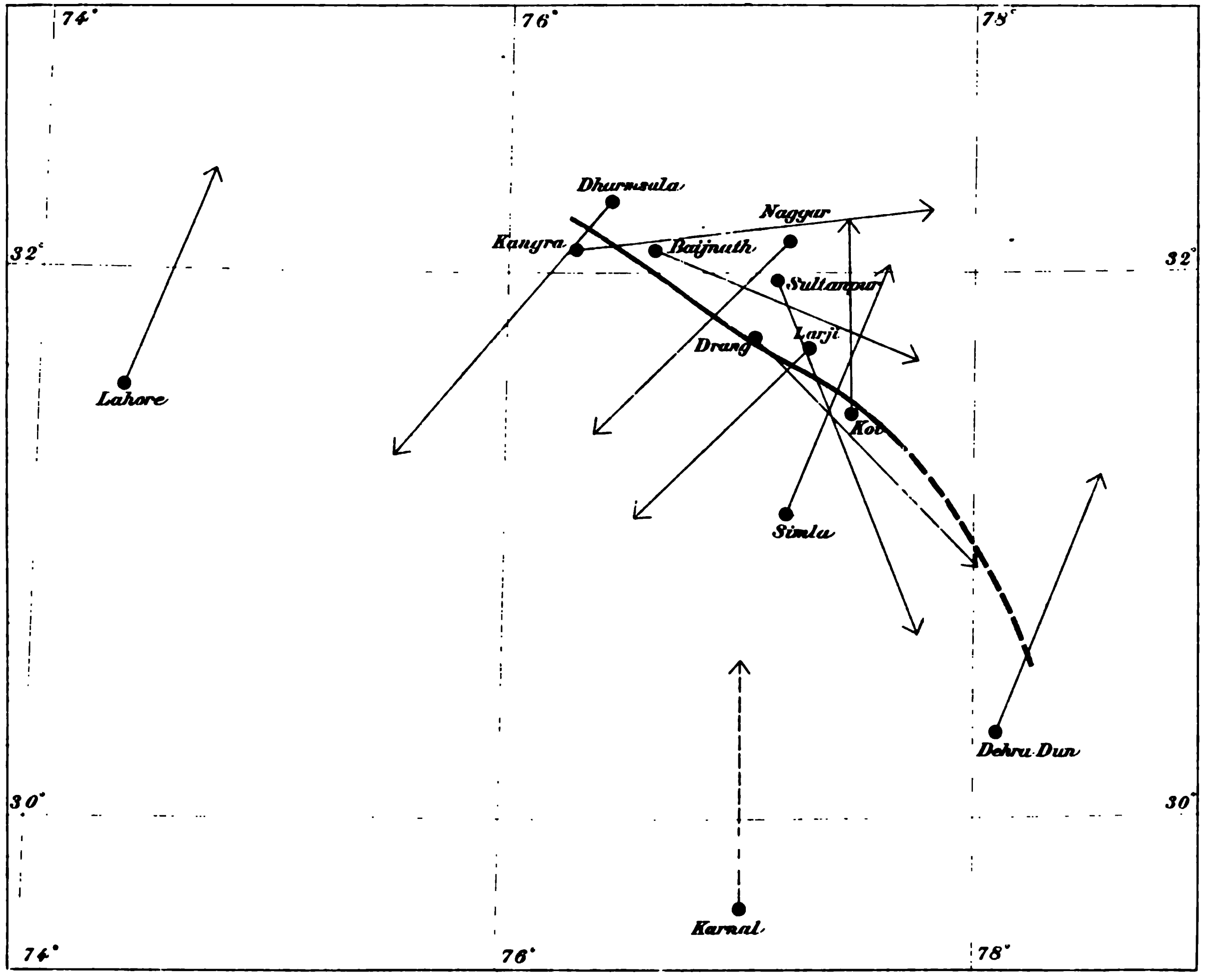
‡ See F. Omori: "Seismic Experiments on the Fracturing and Overturning of Columns." The *Publications*, No. 4.

Pl. II.

Fig. 2. Indian Earthquake of April 4, 1905.

The Direction of Motion and the Epifocal Zone.

Arrow indicates the direction of motion. The thick red line indicates the Epifocal Zone, the dotted part marking its probable south-eastern continuation.



of overturned bodies, or inferred from the comparison of the earthquake effects in the present case with those in the great Mino-Owari (Central Japan) earthquake of 1891, being as follows :—

Simla.	Max. acceleration = about 400 mm/sec^2.
Pathankot.	Motion was weaker than at Simla.
Shahpore.	Motin was much stronger than at Pathankot, and weaker than at Simla.
Rihlu.	Motion was much stronger than at Shapore.
Lahore.	Max. acceleration = about 500 mm/sec^2.
Amritsar.	Motion was slightly weaker than at Lahore.
Delhi	Motion was rather weaker than at Amritsar.
Upper Dharmsala.	Max. acceleration was not greater than 2300 mm/sec^2.
Kangra.	Max. acceleration was not greater than 3500 mm/sec^2.
Palumpur.	Max. acceleration was not greater than 2350 mm/sec^2.
Mandi.	Max. acceleration was not greater than 2280 mm/sec^2.
Naggar.	Motion was stronger than at Simla, but much weaker than at Sultanpur.

Thus it seems that the intensity of motion in the epicentral district of the Kangra earthquake was not so great as in that of the Mino-Owari earthquake of 1891. On the occasion of the latter catastrophe, the maximum acceleration of the earthquake movement in the Mino-Owari plain exceeded 4000 mm/sec^2., that in the epicentral zone of the famous Neo-Valley being much higher. Again, there was, in the Kangra earthquake, no surface manifestation of remarkable faults. These facts seem to indicate that the focus or centre of the earthquake under consideration was very deep below the surface.

4. *Earthquake Damage.* For the account of an absolute scale of strong seismic motion, or the destructive effects corresponding to different values of the maximum acceleration of the earthquake motion, the reader is referred to the *Publications*, No. 4. It is easy to understand that the amount of casualties and the number of houses destroyed by an earthquake depend largely on the method of buildings. Thus, badly built mud or stone houses are completely destroyed by an earthquake shock with an intensity of about 2000 mm/sec^2., while properly built wooden or iron frame structures can resist any shock whatever. One special feature of the seismic effects on structures built with very bad material, which has practically no tensile strength, is that thickness of the walls gives no capacity of resisting seismic force. In fact a massive thick-walled house of inferior masonry work, which has no frame bindings, forms virtually a heap of stone and is simply shattered down at once by an earthquake shock; typical specimens of this sort being the barracks at Dharmsala, where many Gurka soldiers were killed and wounded.

Ordinary buildings in the Kangra Valley, where the shock was strongest, had walls of mud or rubble masonry with a heavy slate roof, being of the worst type of structure with respect to the earthquake shock. The total number of the houses destroyed in the Kangra District and the Mandi State amounted to 112,477, and the number of persons killed reached 18,815, exceeding anything recorded of great seismic catastrophes in the recent times.*

5. ***Direction of Motion and the Earthquake Origin.*** The direction of the maximum earthquake motion at a given place may be assumed to be identical with the mean direction towards which different bodies are mostly overturned.† The directions thus estimated for a number of places in the strongly shaken area of the Kangra earthquake were as follows.

---

* Excepting the north Japan earthquake of June 15, 1896, which caused great tidal disturbances along the north-eastern coast of Japan, resulting in the death of 21,953 persons.

† See the *Publications*, Nos. 4 and 12.

Dharmsala.	Towards	S40°W.
Kangra and *Daulatopur.*	,,	N83°E.
Nagrotha.	,,	W a little S.
Baijnath.	,,	E a little S.
Drang.	,,	SE.
Mandi.	,,	NE—SW (?)
Sultanpur and *Bajaura.*	,,	S a little E.
Between *Sultanpur* and *Naggar.*	,,	NE—SW (?)
Kot.	,,	N.
Larji.	,,	SW.
Dehra Dun and *Mussooree.*	,,	NEN.
Lahore.	,,	N a little E.
Simla.	Towards	N a little E—S a little W.
*Karnal.**	,,	N.

The direction of motion as above given are to be regarded as only gross approximations, the observations being in many instances unsatisfactory or few in number. One marked fact, however, is that the direction at Kangra was towards E a little N, and therefore nearly opposite to that at Dharmsala where the direction was towards SW. Further, comparing together the results for the different places, we see that the latter may be grouped into 2 sets as follows:—

Group *A*:—Lahore, Kangra, Simla, Kot, Dehra Dun, Karnal.

Group *B*:—Dharmsala, Naggar, Baijnath, Sultanpur, Drang, Larji.

At *A* Group places, the direction of motion was towards N, NEN, or ENE, while at *B* Group places it was towards SW, SES, or ESE, so that the maximum earthquake movements at these two different sets of places may be regarded, on the whole, to be opposite to one another, as shown in Fig. 2, probably denoting a certain symmetry of the direction of motion with respect to the earthqnake origin. The red line in the figure, drawn midway between *A* and *B* Group places, is to be regarded as marking the epifocal zone, and the dotted line indicates the possible extension towards the southeast; the entire length of the focus thus supposed being about 270 km or 170 miles. The most central point of the seismic disturbance may be assumed to be situated some distance to the SE of Dharmsala and Kangra, say, at

---

* The direction at Karnal has been inferred from the observation of Mr. Hanly, Assistant Engineer, Dharmsala.

Latitude, **31° 49′** N.
Longitude, **77° 00′** E.

This position has been taken as the earthquake centre in the calculations of the propagation velocities of the different phases of the earthquake motion.

6. *List of Stations.* Table I gives for each of the 69 different stations, where the Kangra Earthquake was observed, the latitude, longitude, epicentral distance ($=x$), and the time ($=t_1$) of earthquake occurrence.* The last named element of motion was deduced from the seismograms, except in the 5 cases marked (*M*), whose epicentral distance was under 21°¾, and whose time of commencement, obtained from magnetogragh records, may be regarded as corresponding to the beginning of the "principal portion."

The times are always given in G.M.T.

The earthquake was insensible at all the places given in the table, except Dehra Dun, where the motion was severe; the nearest and furthest teleseismic stations being respectively Taschkent ($x=11$ 20′) and Tacubaya ($x=128°$ 39′).

---

* The time of earthquake occurrence at the origin itself is given in the next Chapter.

The epicentral distance x has been calculated by the following formula :—

$$\cos x = \sin \phi . \sin \phi_0 + \cos \phi . \cos \phi_0 . \cos(\lambda - \lambda_0),$$

where ϕ and λ denote the latitude and longitude of a given station, and ϕ_0 and λ_0 those of the epicentre.

TABLE I. List of Stations; Observation of the Indian Earthquake of April 4, 1905.

Station.	Position.		Epicentral Distance $=x$	Time of Eqke Occurrence. $=t_1$ (G.M.T.)
	Latitude.	Longitude.		
Epicentre.	**31° 49′ — N**	**77° — — E**	———	**$0^h49^m48^s$** $(=t_0)$
India.				
Dehra Dun.	30°19′19″ N	78°03′19″ E	1° 45′	(M) $0^h50^m38^s$
Colaba (Bombay)	18°53′45″ N	72°48′56″ E	13 28...	0 53 08 (M) 0 57 04
Barrackpur	22°46′29″ N	88°21′39″ E	13° 32′	(M) 0 55 41
Alipore (Calcutta)	22°34′— N	88°24′— E	13 42	0 52 00
Kodaikanal	10°13′50″ N	77°27′46″ E	21 35 ...	0 55 48 (M) 1 01 00
Burma.				
Taungoo.	18°55′45″ N	96°27′03″ E	21° 44′	(M) $1^h00^m03^s$
Russian Turkestan				
Taschkent	41°19′31″ N	69°17′42″ E	11° 20′	$0^h52^m24^s$
Caucasus. (Russia)				
Tiflis	41°43′08″ N	44°47′51″ E	27° 26′	$0^h55^m48^s$
Achalkalaki	41 25 — N	43 29 09 E	28 21	0 55 59
Batum	41 40 — N	41 38 35 E	29 45	0 56 14
Borshom	41 51 — N	43 23 08 E	28 30	0 55 52
Derbent	42 04 — N	48 18 — E	24 58	0 55 03
Schemacha	40 38 — N	48 38 — E	24 23	0 55 09
Siberia.				
Irkutsk	52°16′— N	104°18′33″ E	28° 28′	$0^h55^m44^s$

TABLE I. *Cont.*

Station.	Position.		Epicentral	Time of Eqke Occurrence
	Latitude.	Longitude.	Distance $= x$.	$= t_1$ (G.M.T.)
Asia Minor.				
Bairut	33°54′— N	35°30′— E	34° 41′	$0^h58^m00^s$
Russia.				
Jurjew	58°22′48″ N	26°43′20″ E	42° 49′	0 57 52
Nikolajew	46 58 18 N	31 58 27 E	37 20	0 58 54
Java.				
Batavia	6°08′— S	106°50′— E	42° 35′	0 58 33
Philippines.				
Manila	14°34′41″ N	120°58′33″ E	43° 34′	0 58 25
China.				
Shanghai (Zikawei)	31°11′33″ N	121°10′45″ E	37° 24′	0 53 17
Japan.				
Tōkyō	35°42′33″ N	139°45′53″ E	51° 26′	$0^h59^m08^s$
Mizusawa	39 08 — N	141 07 — E	51 39	0 59 08
Kōbe	34 41 — N	135 11 — E	48 03	0 58 26
Ōsaka	34 42 — N	135 31 — E	48 19	0 58 51
Tadotsu.	34 17 — N	133 46 — E	47 02	0 58 49
Formosa (Japan).				
Taihoku	25°02′— N	121°30′— E	39° 27′	0 57 19
Taichu	24 09 — N	120 42 — E	39 05	—
Tainan	22 59 — N	120 12 — E	39 06	—
Mauritius.	20°11′— S	57°31′— E	55° 15′	0 58 54
Servia.				
Belgrade.	44°48′— N	20°09′— E	45° 29′	0 57 47
Germany.				
Potsdam.	52°22′56″ N	13°03′59″ E	49° 48′	$0^h58^m46^s$
Leipzig.	51 20 06 N	12 23 30 E	50 16	0 58 44
Jena.	50 56 — N	11 35 — E	50 48	0 58 54
Hamburg.	53 33 55 N	10 01 19 E	51 34	0 58 14
Göttingen.	51 33 — N	9 58 — E	51 45	0 58 55
Strassburg.	48 35 00 N	7 46 10 E	53 31	0 58 26

TABLE I. *Cont.*

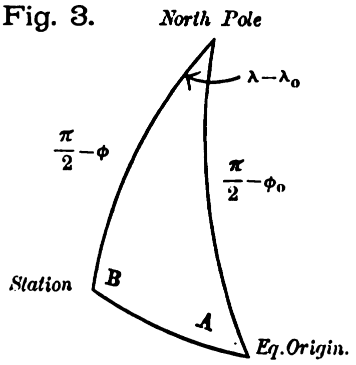
Station.	Position.		Epicentral Distance $=x$.	Time of Eqke Occurrence $=t_1$ (G.M.T.)
	Latitude.	Longitude.		
Austria-Hungary.				
Krakau	50°03′50″ N	19°57′36″ E	45° 30′	$0^h58^m12^s$
Laibach	46 03 — N	14 30 — E	49 19	0 58 46
Triest.	45 38 45 N	13 45 45 E	49 52	0 58 44
Pola.	44 51 49 N	13 50 44 E	49 55	0 58 50
Sweden.				
Upsala.	59°51′30″ N	17°37′30″ E	47° 41′	0 58 22
Italy.				
Messina.	38°11′45″ N	15°33′18″ E	49° 46′	0 59 00
Port d'Ischia.	40 44 27 N	13 56 34 E	50 30	0 58 56
Rocca di papa.	41 46 — N	12 42 — E	51 15	0 58 51
Querce (Florence).	43 47 18 N	11 16 42 E	51 54	0 59 08
Ximeniano. („)	43 46 40 N	11 15 24 E	51 55	0 58 33
Quarto-Castello („)	43 49 11 N	11 13 11 E	51 56	0 58 47
Padova.	45 24 3 N	11 52 18 E	51 20	0 58 58
Great Britain.				
Kew	51°28′06″ N	0°18′46″ W	58° 05′	1 00 12
Edinburgh.	55 57 23 N	3 10 46 W	58 48	1 00 00
Birmingham.	52 28 — N	1 53 — W	58 49	1 00 35
Shide (I. W.)	50 42 — N	11 9 — W	58 52	1 01 00
Liverpool (Bidston).	53 24 04 N	3 04 18 W	59 18	1 00 36
Paisley.	55 51 — N	4 25 — W	59 30	1 00 00
Spain.				
San Fernando.	36°27′40″ N	6°12′19″ W	66° 47′	1 02 30
Azores.				
Ponta Delgada.	37 46 — N	25 41 — W	79 54	1 01 00
Cape of Good Hope.	33 56 03 S	18 28 41 E	85 46	1 02 30
Canada.				
Victoria, B.C.	48 27 — N	123 22 — W	97 42	1 06 48
Toronto.	43 39 36 N	79 23 24 W	101 30	1 06 36
Hawaii.				
Honolulu.	21 19 — N	153 04 — W	108 27	1 04 36

TABLE. I. *Cont.*

Station.	Position.		Epicentral Distance $=x$.	Time of Eqke Occurrence $=t_1$ (G.M.T.)
	Latitude.	Longitude.		
United States.				
Baltimore.	39°17′48″ N	76°37′12″ W	104° 47′	1h10m30s
Washington.	38 54 18 N	77 03 06 W	105 17	1 08 25
Cheltenham	38 44 00 N	76 50 30 W	105 22	1 08 39
Porto Rico.				
Vieques.	18 09 — N	65 26 — W	118 25	1 10 25
Samoa (Apia)	13 48 24 S	171 45 54 W	115 08	1 01 36
New Zealand.				
Christchurch.	43 31 50 S	172 37 18 E	115 03	1 10 00
Wellington.	41 17 — S	174 47 — E	115 45	1 09 48
Brazil.				
Rio de Janeiro.	22 54 24 S	43 10 21 W	126 53	1 59 41 (?)
Mexico.				
Tacubaya.	19 24 18 N	99 11 37 W	128 39	1 11 25

7. ***Directions of Observing Stations relative to the Earthquake Origin.*** Table II gives, for a number of the observing places, besides the epicentral arcual distance (x) expressed in km, the azimuth (A) of a given station with respect to the earthquake origin, and the azimuth (B) of the latter with respect to the former, both counted from the north.* (See Fig. 3, in which ϕ and ϕ_0 have

Fig. 3.



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* This calculation has very kindly been undertaken by Mr. K. Ōi, Assistant Professor in the Science and Engineering College, Kyōto Imperial University.

the same meanings as in the preceding §). The azimuths A and B have been calculated by the following formulae:—

$$\sin A = \frac{\cos\phi.\ \sin(\lambda-\lambda_0)}{\sin x};$$

$$\sin B = \frac{\cos\phi_0.\ \sin(\lambda-\lambda_0)}{\sin x}.$$

TABLE II. Distance and Azimuth of Observing Stations.

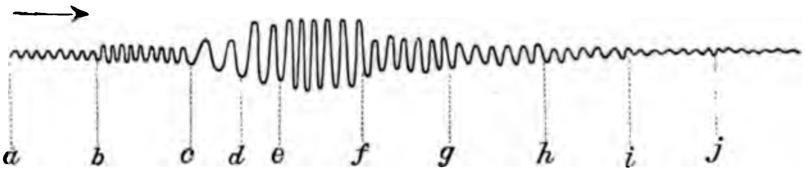
Station.	Epicentral Distance.		Azimuth *A*. (from North)	Azimuth *B*. (from North)
	in Angle.	in km.		
Tiflis.	27°26′06″	3050	W 59°41′37″	E 79°22′20″
Osaka.	48 19 11	5372	E 69 50 31	W 75 59 26
Potsdam.	49 47 46	5536	W 42 52 56	E 88 02 40
Tokyo.	51 25 47	5718	E 67 25 58	W 75 05 36
Göttingen.	51 45 10	5754	W 46 48 18	E 85 01 10
Quarto-Castello.	51 56 07	5774	W 56 41 45	E 79 49 50
Kew.	58 05 04	6458	W 45 43 22	E 77 35 10
San Fernando.	66 47 11	7425	W 60 20 17	E 66 39 00
Toronto.	101 29 49	11285	W 17 11 54	E 20 19 16
Washington.	105 16 39	11705	W 20 40 11	E 22 40 14
Cheltenham.	105 22 21	11716	W 20 53 42	E 22 51 43
Christchurch.	115 03 11	12792	E 127 12 26	W 68 59 01
Wellington.	115 44 30	12868	E 124 15 11	W 69 10 26
Rio de Janeiro.	126 53 19	14108	W 96 10 58	E 66 32 04
Tacubaya.	128 38 55	14303	W 4 35 54	E 4 08 31

As will be seen from the above table, Tacubaya lies very nearly on the meridian passing through the earthquake centre; while the azimuth (B) for Tiflis, Osaka, Tokyo, Potsdam, Göttingen, Quarto-Castello, and Kew, is not much different from 90°, varying between 75° and 88°. It may be concluded, therefore, that the NS and EW components of the seismogram at Tacubaya corresponded almost exactly to the *longitudinal* and *transverse waves* respectively. On the contrary, the same two components at the

7 other above named stations approximately corresponded to the *transverse* and *longitudinal waves*, respectively. Of the remaining places given in the table, Toronto, Washington, and Cheltenham, are situated not very much out of the meridian through the origin of disturbance, while the azimuth for San Fernando, Christchurch, Wellington, and Rio de Janeiro, was nearly 70°. The approximate relation to the position of the earthquake centre of the other stations not above mentioned may be inferred from that for those places given in the table.

8. *Character of the Teleseismic Motion.* The earthquake motion due to a distant origin consists generally of a series of different sections or stages, in each of which the period* remains essentially constant, while the amplitude is also on the whole constant, except for the occurrence of maximum and minimum groups.

Fig. 4.



The successive sections of the earthquake motion, illustrated in Fig. 4, are as follows.

The *preliminary tremor* (*a b c*), which consists principally of vibrations of small amplitude and of comparatively short period, is divided into the 1st *section* or the *first preliminary tremor* (*a b*), and the 2nd *section* or the *second preliminary trmor* (*b c*). Commencement of the latter is marked by an increase of the amplitude and, in many cases, also by the appearance of slow vibrations.

---

* The term "Period" is used in the sense of the *complete period.*

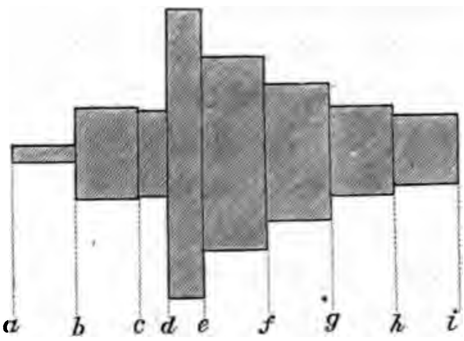
The *principal portion*, which comprises the 3rd to 7th *sections* (*cd, de, ef, fg, gh*), denotes the most active part of an earthquake, which follows the preliminary tremors and consists of movements of larger amplitude. The subdivisions of the *principal portion* are as follows:—The *1st phase* (3rd *section*), consisting of a few very slow vibrations; the *2nd phase* (4th *section*), consisting also of slow movements whose period is somewhat shorter than in the 1st phase; the *3rd phase* (5th *section*), consisting of vibrations of period much quicker than that in the preceding two phases; the *4th phase* (6th *section*) and the *5th phase* (7th *section*), the vibrations in these two stages being quicker and smaller than in the 3rd phase.

Lastly, the *end portion*, or *tail*, which comprises the 8th and subsequent *sections*, (*h i*, ...) denotes the feeble finishing part of the earthquake motion, following the principal portion.

In earthquakes of near origin, the motion is, on account of the predominance of quick vibrations of macro-seismic character, much more complex than in distant earthquakes, it being generally difficult to subdivide the principal portion into the different phases.

Range of Motion (Double Amplitude) and Duration. The relative magnitudes of vibrations in the successive sections, or stages, of the teleseismic disturbance are different from those of the near earthquake motion, the predominating periods in each epoch being different according to the epicentral distance. In the case of the 11 large distant earthquakes observed between 1899 and 1902 in Tokyo, the relative magnitudes of motion in the successive sections of motion were as shown in the 2nd column of Table III. From the latter it will be seen that the range of motion in the 1st preliminary tremor (1st section) was only about $\frac{1}{5}$th or $\frac{1}{6}$th of that in the 2nd and 3rd sections, namely, the 2nd preliminary tremor and the 1st phase of the principal portion; the 2nd phase (4th section) of the latter having the maximum motion, which is more than 3 times greater than those in the two preceding sections. The ranges in the 3rd and 4th phases of the principal portion were respectively about 12 and 8 times greater than that in the 1st preliminary tremor. The motion in the next phase, 7th section, was equal to that in the 2nd preliminary tremor and the succeeding phase, and may be regarded as forming the finishing part of the principal portion; the 8th section, whose motion was still smaller, properly belonging to the tail or end portion. As shown in the 3rd column of Table III, the durations of the successive sections of motion were roughly equal to one another, the 1st and 2nd phases of the principal portion being taken together. Fig. 5 gives a diagramatic representation of the teleseismic motion, so far as the durations and amplitudes are concerned.[*]

Fig. 5.



ab ......1st Section, or 1st Prel. Tremor.
bc ......2nd „ , „ 2nd „ „
cd ......3rd Section, 1st Phase, Princ. Portion.
de ......4th „ , 2nd „ , „ „
ef ......5th „ , 3rd „ , „ „
fg ......6th „ , 4th „ , „ „
gh ......7th „ , 5th „ , „ „
hi ..... 8th „ Tail, or End Portion.
....

Periods. There are a number of periods occurring in different parts of the earthquake motion. Amongst others, the two periods denoted by P_1 and P_2 occur very often,[*] being respectively identical with the two periods Q_1 and Q_2 of the "pulsatory oscillations." Other periods of microseismic or insensible nature, which are of a more or less frequent occurrence may be denoted by $\boldsymbol{P}_3$, $\boldsymbol{P}_4$, $\boldsymbol{P}_5$, ...$\boldsymbol{P}_{13}$,....... The average values of the different periods are as follows :—

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[*] See the *Publications*, No. 13.

$P_1 = 4.2$ sec.	$P_8 = 32.3$ sec.
$P_2 = 8.7$ „	$P_9 = 35.4$ „
$P_3 = 14.1$ „	$P_{10} = 41.8$ „
$P_4 = 17.5$ „	$P_{11} = 45.0$ „
$P_5 = 20.4$ „	....
$P_6 = 24.9$ „	$P_{13} = 54.0$ „
$P_7 = 28.3$ „	....

In the 4th column of Table III, which gives the periods of the predominating vibrations in the different sections of motion of the same 11 great teleseismic disturbances, those of a specially frequent occurrence are printed in fat characters.

TABLE III. Amplitude, Duration, and Periods of Great Teleseismic Motion. (Tokyo Observation, 1899–1902.)

Phase of Motion.	Relative Amplitude.	Relative Duration.	Predominating Periods.
1st Preliminary Tremor.	100	100	P_1; $\boldsymbol{P}_2$; P_3
2nd „ „	560	95	P_1; $\boldsymbol{P}_2$; P_3; —; —; P_6; P_7
1st Phase, Princ. Portion.	550	$\left.\begin{matrix}30\\49\end{matrix}\right\}79$	—; P_2; ... P_9; P_{10};... P_{13}
2nd „ „ „	1820		—; P_2; ... P_7; $\boldsymbol{P}_9$; P_{10}
3rd „ „ „	1220	91	..........$\boldsymbol{P}_5$; P_6
4th „ „ „	840	95	—; P_2; $\boldsymbol{P}_3$; P_5
5th „ „ „	560	95	—; P_2; $\boldsymbol{P}_3$
8th Section (Tail)	430	88	—; —; $\boldsymbol{P}_3$
End Portion (Tail).	—	—	—; $\boldsymbol{P}_2$; P_3; P_5

As will be seen from the above table, the period P_2 (=8,7 sec.), which occurred very frequently in the 1st and 2nd preliminary tremors, happened more or less almost through the entire series of the different sections of motion. In the 2nd preliminary tremor, slow periods of P_6 (=24.9 sec.) and P_7 (=28.3 sec.) began to appear; while in the 1st phase of the principal portion, very slow periods of P_{10} (=41.8 sec.) and P_{13} (=54.0 sec.), were of a frequent occurrence. In the 2nd phase of the same portion, the predominating period became a little shorter and P_9 (=35.4 sec.) occurred very often. In the 3rd phase of the principal portion, the vibrations still further quickened, the period of P_5 (=20.4 sec.) occurring most frequently. In the two subsequent phases of the principal portion and the 1st phase of the tail, the predominating period was P_3 (=14.1 sec.). Towards the end of motion the period of common occurrence became again P_2 (=8.7 sec.), being the same as that prominent in the 1st and 2nd preliminary tremor.

The foregoing short account of the teleseismic motion, based on the previous observations made in Tokyo, has been given for the sake of reference, the complete discussion on the character of the vibrations being reserved for a later chapter.

9. *Time of Occurrence of the Kangra Earthquake.*

(i) *Time of Earthquake Occurrence inferred from Teleseismic Records.*

The time ($=t_0$) of earthquake occurrence at the origin itself may be estimated by the following formula*:—

$$t_0=t_1-1.165\ y_1 \ \dots\dots\dots\dots\dots (1)$$

in which t_1 and y_1 denote respectively the time of commencement, and the duration of the 1st preliminary tremor, of the earthquake motion at a given observing station. This equation is to be regarded as being roughly approximate, but seems to give fairly satisfactory results; the time of occurrence at the origin, estimated by (1), agreeing in the cases of the Calabrian earthquake of Sept. 8, 1905, and of the San Francisco earthquake of April 18, 1906, almost to within 1 minute.

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* The *Bulletin of the Imperial Earthquake Investigation Committee*, Vol. 1, No. 1.

For the time of commencement (t_0) of the Kangra earthquake, we have, applying, for example, the Tokyo observation to the equation (1):—

$$t_1 = 0^{h}\ 59^{m}\ 08^{s}\ (\text{G.M.T.});\ y_1 = 7^{m}\ 16^{s}.$$
$$t_0 = 0^{h}\ 59^{m}\ 08^{s} - (1.165 \times 436s) = 0^{h}\ 50^{m}\ 40^{s}\ (\text{G.M.T.})$$

Again, taking the averages from the observations at the 18 stations of Tokyo, Osaka, Mizusawa, Tadotsu, Kobe, Upsala, Laibach, Triest, Pola, Potsdam, Leipzig, Göttingen, Messina, Ischia, Rocca di papa, Querce, Ximeniano, and Quarto-Castello, whose epicentral distance varied between 47° 02′ and 51° 56′, we obtain:—

$$\textit{mean}\ t_1 = 0^{h}\ 58^{m}\ 58^{s}\ (\text{G.M.T.});\ y_1 = 7^{m}\ 12^{s}$$
$$t_0 = 0^{h}\ 58^{m}\ 58^{s} - (1.165 \times 432^{s}) = 0^{h}\ 50^{m}\ 35^{s}\ (\text{G.M.T.})$$

These values of t_0 agree very well with the time of occurrence at the origin inferred from the magnetograph observations made at Dehra Dun, namely, 0h 49m 48s, G.M.T. (See the next §.)

(ii) *Earthquake Recorded by Magnetographs.*

The only instrumental record of the shock within the meizoseismal area is that given by the magnetograph at Dehra Dun, which is thus extremely valuable in connection with the determination of the time of earthquake occurrence at the origin of disturbance. The following detailed account respecting the magnetograms obtained at Dehra Dun and three other stations of Barrackpore (near Calcutta), Kodaikanal (Madras), and Taungoo (Burma), has very kindly been furnished by Captain Thomas, the officer in charge of the Magnetic Department at Dehra Dun, and his assistant, Mr. Mazumdar; a very useful check on the time found for each place consisting in comparing the interval between the earthquake shock and a well marked apex in magnetic disturbances either preceding or following the latter.

"On the Time of the Principal Earthquake Shock on the 4th April 1905 as registered on Magnetograph Curves.

"*Accuracy of Measurement*......The process of measuring the exact moment of time of a particular point on the trace is burdened with several sources of error, in the measurement of small quantities.

"......The accordance, however, of many of the results in the following §§ when independent measures were taken by two or more observers, is such that there should be no hesitation in accepting some groups as correct at least to 1 minute of time.

"There is moreover a check on the times found for each observatory, by comparing the intervals derived from the time of shock at each observatory with the intervals obtained by measuring the interval between the shocks and the well marked apices of disturbances on the same date.

"......Two apices of disturbance have been utilized and the measurement has been made in two ways. An additional advantage applies to these methods in that error of cut off, parallax, and error of clock are not involved.

"In the first the absolute time of the apex of disturbance is found and the time interval derived by applying the absolute time of the shock already determined.

"In the second the interval is measured direct ....

"*Method of obtaining Time at the various observatories.* Before tabulating the results of the measurements of the magnetograms, and comparing them as above suggested, it would be well to briefly indicate the methods of obtaining correct time at the various observatories.

"At Dehra Dun time is obtained by comparision of the observer's chronometer with the sidereal clock at least twice a week, errors on other days being interpolated by the rates thus obtained.

"At Barrackpore and Taungoo time is obtained by observations to E and W stars.

"At Kodaikanal time is obtained by telegraphic signal from Madras daily and the observer's chronometer is compared daily with the Solar Physics Observatory clock.

"At all observatories the driving clock of the magnetographs is compared daily with the standard chronometer by means of a pocket chronometer but as before stated in the absence of a second hand on the driving clock, this determination is likely to be in error some seconds.

Time of principal shock measured from magnetographs.

"I. Direct measurement of time of shock. (All in Madras time, corrected for errors of clock, parallax and cut off).

Observer*		Capt. Thomas	Mazumdar	Omori
Delhra Dun ...	(*H*)	6^h—11^m—43^s	6^h—11^m—29^s	6^h—11^m—27^s
	(δ)	6—11—48	6—11—46	6—11—33
		(*Mean*=6 —11—38.)		
Barrackpore ..	(*H*)	6—16—12	6—16—26	6—16—29
	(δ)	6—17—5	6—16—50	6—16—55
		(*Mean*=6—16—41)		
Kodaikanal...	(*H*)	6—21—40	6—21—37	6—21—30
	(δ)	6—22—4	6—22—36	6—22—30
		(*Mean*=6—22—0)		
Taungoo	(*H*)	6—20—3	6—19—45	6—19—58
	(δ)	very faint—not measured		
		(*Mean*=6—19—55)		

These give intervals:—

Dehra Dun—Barrackpore = 5^m—03^s

„ —Kodaikanal = 10—22

„ —Taungoo = 8—17

---

* H from HF curve; δ from Decl. curve.

"II. Measurement of time interval between an apex (*a*) of magnetic disturbance and time of the earthquake shock.*

(*i*) Absolute time of apex of disturbance (*a*).

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
9^{h}—12^{m}—22^{s}	9^{h}—12^{m}—09^{s}	9^{h}—12^{m}—21^{s}	9^{h}—11^{m}—11^{s}

Subtracting these values from the time of principal shock we get:—

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
3— 0 —41	2—55—35	2—50—21	2—51—17

This gives times for interval:—

Dehra Dun—Barrackpore = 5^{m}—06^{s}
" —Kodaikanal = 10—20
" —Taungoo = 9—24

(*ii*) Direct measurement of time interval.

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
3— 0 —30	2—55—22	2—50—17	2—51—3

This gives times for interval:—

Dehra Dun—Barrackpore = 5^{m}—09^{s}
" —Kodaikanal = 10—08
" —Taungoo = 9—28

" III. Absolute time of an apex of magnetic disturbance (*b*).

(*i*) Dehra Dun	Barrackpore	Kodaikanal	Taungoo
2—31—46	2—31—40	2—31—45	2—30—35

Subtracting time of principal shock we get:—

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
3—40—00	3—44—59	3—50—15	3—49—38

The differences are:—

Dehra Dun—Barrackpore = 4^{m}—59^{s}
" —Kodaikanal = 10—15
" —Taungoo = 9—38

(*ii*) Direct measurement of interval from apex (*b*) to principal shock.

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
3—39—51	3—44—54	3—49—55	3—49—16

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* The measurements here given are the means of those made by Capt. Thomas and Mr. Mazumdar separately.

These give the time differences:—

Delhra Dun—Barrackpore = 5^{m}—03^{s}
„ — Kodaikanal = 10—04
„ —Taungoo = 9—25.

"IV. Absolute times of disturbances. As found these are

	Disturbance (*b*)	*mean*	Disturbance (*a*)	*mean*	Difference (*a*)-(*b*)
Delhra Dun	2—31—46	2—31—44	9—12—22	9—12—17	6—40—36
Barrackpore	2—31—40		9—12—09		6—40—29
Kodaikanal	2—31—45		9—12—20		6—40—35
Taungoo	2—30—35		9—11—11		6—40—36

Difference, *Mean*—Taungoo = 1^{m} 08^{s}

This proves that the disturbances are simultaneous at all observatories within the limits of measurement and that Taungoo time is slow 1^{m} 08^{s} while the time at the other three observatories is very good. This conclusion is further borne out by consideration of the interval Delhra Dun-Taungoo by the two methods of measurement.

	Delhra Dun-Taungoo
By direct measurement of time of shock	8^{m}—17^{s}
By measurement from magnetic disturbances (which eliminates error of clock)	9^{m}—27^{s}

or Taungoo time slow 1^{m} 10^{s}
and mean correction to Taungoo + 1^{m} 09^{s}

"V. Comparisons of the intervals of time found from Delhra Dun to the other observatories.

Delhra Dun—Barrackpore:—

		mean
(*i*) Direct measurement	5^{m}—3^{s}	5^{m}—04^{s}
(*ii*) By measurement from disturbances	5 —5	

Delhra Dun—Kodaikanal:—

(*i*) By direct measurement	10—22	10—18
(*ii*) By measurement from disturbances	10—13	

This shows that the clock times at Delhra Dun, Barrackpore and Kodaikanal are practically correct.

"VI. Final values of time of principal shock. For the reasons shown in V there is no good reason for not accepting the times given for Dehra Dun, Kodaikanal, and Barrackpore; the only correction is then to add $1^m\ 08^s$ to the Taungoo time.

The times then become:—

	(Madras Time)		(G.M.T.)
Dehra Dun	6—11—38	=	0—50—38
Barrackpore	6–16–41	=	0—55—41
Kodaikanal	6—22—00	=	1—01—00
Taungoo	6—21—03	=	1—00—03

(iii) *The Probable Time of Earthquake Occurrence at the Origin.* Thus the time of earthquake disturbance as registered by the magnetograph at Dehra Dun was $0^h\ 50^m\ 38^s$, G.M.T., the approximate distance of that place from the most central part of the epifocal zone being 1° 45′, or 195 km. Within such an epicentral distance, the velocity of propagation of the 1st preliminary tremor is probably 5 or 6 km per sec. If we assume the velocity to be 6 km per sec., the time taken by the seismic waves in travelling the distance of 195 km would be about 32 sec. Now, as the magnetograph is not so sensitive as a seismograph, the time moment recorded at Dehra Dun might correspond to the commencement of the principal portion, the duration of the total preliminary tremor being probably some 20 sec. Thus the time of earthquake occurrence at the epicentre may approximately be taken as $0^h\ 50^m\ 38^s$ minus about 50 sec., or

$$t_0=0^h49^m48^s \quad \text{(G. M. T.)}$$

10. ***Comparison of Magnetic and Seismographic Records.***

(i) According to the Milne horizontal pendulum seismogram at Calcutta, the times of commencement of the 1st preliminary tremor and the principal portion were respectievly 0 $52^m\ 00^s$

and $0^h\ 55^m\ 24^s$ G.M.T. But according to the magnetograph record obtained at Barrackpore, which is not far from the above-mentioned place, the earthquake disturbance began first at $0^h 55^m 41^s$.

(ii) At Colaba, Bombay, the times of commencement of the 1st preliminary tremor and the principal portion were, according to the "Colaba" seismograph, $0^h\ 53^m\ 08^s$ and $0^h\ 56^m\ 39^s$, respectively. The times of the earthquake disturbance indicated by the magnetographs were as follows :—

H. F. Magnetograph,	$0^h 56^m 44^s$
D. ,, ,	0 57 14
V. F. ,, ,	0 57 14
Mean............	0 57 04

The commencement of the disturbance registered by the barograph was $0^h 56^m 44^s$, being practically identical with that indicated by the magnetographs.

(iii) The times of commencement of the earthquake motion at Kodaikanal were as follows :—

Milne Hor. Pend.....	Commencement of 1st Prel. Trem.,	$0^h 55^m 48^s$
	,, Prnic. Port.,	0 59 43
Magnetograph		1 01 00

From the preceding comparisons, it will be seen that the disturbances recorded by the different magnetographs were nearly simultaneous with the principal portion in the seismograms.

(iv) The commencement of the disturbance in the Taungoo magnetograph, which happened at $1^h\ 00^m\ 03^s$, must also evidently be that of the principal portion.

The above magnetograph observations may be divided into two groups, according to the epicentral distances, as follows ;—

Group.	Place.	Epicentral Distance.	Time of Commencement.	Time interval required by radial propagation.
A	Barrackpore.	13° 32′	$0^h\ 55^m\ 41^s$	$5^m\ 53^s$
	Bombay.	13 28	0 57 04	7 16
	Mean......	**13 30**	**0 56 23**	**6 35**
B	Kodaikanal.	21° 35′	$1^h\ 01^m\ 00^s$	$11^m\ 12^s$
	Taungoo	21 44	1 00 03	10 15
	Mean......	**21 40**	**1 00 32**	**10 44**

The "direct method" calculation† gives the following values of the transit velocity :—

Group (*A*) ....3.80 km per sec.
Group (*B*) ....3.73 „ .
Mean................3.77 „

This approximately corresponds to the transit velocity of the 1st phase of the principal portion. The "difference mothod" calculation† gives :—

velocity = 3.65 km per sec.

11. ***Analysis of Seismograms.*** The seismograms which I have analysed were nearly 70 in number, and related to the following 51 stations :—*Tōkyō* (*Hongō, Hitotsubashi,* and *Central Meteorological Observatory*) ; *Mizusawa* ; *Ōsaka* ; *Kōbe* ; *Tadotsu* ; *Taihoku* ; *Taichu* ; *Tainan* ; *Dehra Dun**; *Barrackpore**; *Bombay* (*Colaba*) ; *Taungoo**; *Calcutta* (*Alipore*) ; *Kodaikanal* ; *Shanghai* (*Zikawei*) ; *Batavia* ; *Manila* ; *Laibach* ; *Pola* ; *Triest* ; *O'-Gyalla* ; *Florence* (*Ximeniano* ; *Querce* ; and *Quarto Castello*) ; *Ischia* ; *Rocca di Papa* ;

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† See the *Bull. Imp. Earthquake Inv. Comm.*, Vol. I, No. 1.

* For those stations marked with *asterisks*, we have only magnetograph records of the earthquake.

Potsdam; *Strassbury*;* *Göttingen*; *Leipzig*; *Upsala*; *Birmingham*; *Shide*; *Kew*; *Liverpool* (*Bidston*); *Edinburgh*; *Paisley*; *San Fernando*; *Mauritius*; *Cape of Good Hope*; *Toronto*; *Victoria, B.C.*; *Baltimore*; *Washington*; *Cheltenham*; *Tacubaya*; *Wellington*; *Christchurch*; *Rio de Janeiro.*

All the analyses have been made on the supposition that the vibrations recorded represent the movements of a particle of the ground, which are either rectilinear or curvilinear, but which can be resolved into horizontal and vertical components, and not the effects due to the tilting or inclination of the ground; that is to say, the range of motion has been obtained in each case by dividing the actual trace on the seismogram by the multiplication ratio of the pointer of the instrument. (See the *Publications*, No. 5.)

The elements of the earthquake motion relating to the following 21 stations, from which I did not get copies of the seismograms, have been taken from various monthly, weekly, and other seismological reports:—*Taschkent*; *Tiflis*; *Achalkalaki*; *Batum*; *Borshom*; *Derbent*; *Schemacha*; *Jurjew*; *Nikolajew*; *Irkutsk*; *Apia* (Samoa); *Vieques* (Porto Rico); *Honolulu*; *Bairut* (Syria); *Ponta Delgada* (Azores); *Belgrade*; *Krakau*; *Jena*; *Hamburg*; *Padova*†; *Messina.*

In the descriptions of the seismograms given in the succeeding chapters, the times are, unless otherwise stated, always given in the Greenwich Mean Civil Time. The symbols $2a$ and T denote respectively the range of motion (double amplitude) and the complete period of seismic vibration; a displacement, which is to be regarded as a single amplitude, being denoted by a.

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* The photographic reproduction of the Strassburg registers were too faint, and I was not able to analyse them.

† The copy of the Padova seismogram had unfortunately neither time marking nor scale of magnitude, so that I have taken the elements of motion from the seismological bulletin issued by Prof. Vicentini.

The seismograms obtained at the different stations have been given in Pls. I to XXII of the *Publications*, No. 23.

Chapter II. Open or large time-scale Diagrams of the Kangra Earthquake, furnished by mechanically or photographically registering instruments.

12. ***List of the Seismograms.*** The diagrams described in this chapter are those registered either mechanically or photographically by the different seismographs, whose record-receiver moved at a sufficiently high rate, enabling us to measure the amplitude and period of the individual vibrations. The following is the list of the seismograms which I have examined

(1) Hongō, Tōkyō : EW Component.
(2) „ „ : NS „
(3) „ „ : Vertical „
(4) Hitotsubashi, „ : EW „
(5) Hongō, „ : EW „ (Tromometer Record).
(6) Central Met. Observatory, Tokyo : EW Component. („).
(7) Ōsaka : EW Component.
(8) Kōbe : NS „
(9) Tadotsu : EW „
(10) Taihoku : „ „
(11) Taichu : „ „
(12) Tainan : „ „
(13) O'Gyalla : EW and NS Components,
(14) Birmingham : EW Component,

(15) Washington : NS Component.
(16) Cheltenham : EW ,,
(17) ,, : NS ,,
(18) Tacubaya : EW ,,
(19) ,, : NS ,,
(20) Quarto-Castello : EW ,,
(21) ,, : NS ,,
(22) Ximeniano : Horizontal and Vertical Components.
(23) Ischia : NS and EW Components.
(24) Laibach : Horizontal and Vertical Components.
(25) Pola : NS and EW Components.
(26) Triest : Horizontal and Vertical Components.
(27) Manila : Horizontal Components.
(28) Rocca di papa : ,, ,,
(29) Colaba : Horizontal and Vertical Components.
(30) Potsdam : EW Component.
(31) ,, : NS ,,
(32) Göttingen : EW ,,
(33) ,, : NS ,,
(34) Leipzig : EW ,,
(35) ,, : NS ,,
(36) Upsala : NS ,,
(37) ,, : EW ,,
(38) Batavia : EW ,,
(39) Shanghai : EW ,,
(40) Rio de Janeiro : EW ,,
(41) Strassburg.

To the detailed accounts relating to the above mentioned seismograms, (the three last ones excepted), are added short statements of the elements of motion at the following stations :—

Irkutsk; Taschkent; Tiflis and 5 other Caucasian stations; Jurjew; Nikolajew; Belgrade; Krakau; Padova; Messina; Jena; Hamburg; Vieques (Porto Rico); Apia (Samoa).

OBSERVATIONS IN TOKYO, JAPAN.

13. ***Time of Earthquake Occurrence in Tokyo.*** The motion was intense enough to be recorded even by an ordinary Gray-Milne seismograph at the Central Meteorological Observatory, the time of earthquake occurrence there registered being $0^h 59^m 46^s$, which very nearly corresponds to the commencement of the 1st preliminary tremor.

The time of the earthquake occurrence deduced from the diagrams furnished by the different instruments set up in the Seismological Institute (Hongō, Tokyo), was as follows:—

EW COMPONENT..	Hor. Pend. Tromometer	(§17)	0^h	59^m	06^s
	Hor. Pendulum (*A*)*		0	59	05
	Hor. Pendulum	(§14)	0	59	18
NS „	Hor. Pendulum	(§15)	0	59	11
VERTICAL „	....	(§16)	0	59	07

The slight inequalities in the times of occurrence given above were due in a great measure to the existence of small pulsatory oscillations, which somewhat obscured the beginning of the very first preliminary movements, except in the tromometer record in which the commencement was sharply indicated. Properly taking the mean of all the above determinations, the time of earthquake occurrence in Tokyo is found to be

$$0^h\,59^m\,8^s \quad \text{(G.M.T.)}$$

The earthquake was also recorded by a horizontal pendulum at the Seismological Station of Hitotsubashi, and by a horizontal pendulum tromometer at the Central Meteorological Observatory, so that the number of the teleseismic records in Tokyo was altogether seven. The 5 better ones of these are described in detail in the succeeding §§. All the instruments at Hongō are set up in the brick " Earthquake-proof House."*

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* This is the same as (*A*) Apparatus described in the *Publications*, No. 5.

14. ***EW Component at Hongō, Tokyo.*** (See Pl. I, the *Publications*, No. 23.) The record was furnished by a long-period Omori Horizontal Pendulum (*C*-Apparatus, described in the *Publications*, No. 5), whose constants were as follows :—

Vertical distance between the point of suspension and the point of support = 2.65 metres.

Length of the strut, or the horizontal distance between the centre of the heavy bob and the point of support = 1 metre.

Weight of the heavy bob = 17.4 kg.

Multiplication of the pointer = 15.

Oscillation period of the horizontal pendulum = 61.5 sec.

This seismograph and all the other teleseismic instruments in use in Japan have no damping arrangement. The ground at Hongō is 19 m above the sea level and consists of hard loam.

1st Preliminary Tremor lasted $7^m\ 17^s$, and began with a maximum vibration, whose two displacements were as follows :—

$$\begin{cases} \text{1st motion} \ldots\ldots\ a = 0.37\ \text{mm, towards W;} \\ \text{2nd motion} \ldots\ldots 2a = 0.57\ \text{mm,} \quad ,, \quad \text{E;} \end{cases}$$

Another maximum $2a = 0.57$ mm, $T = 24.7$ sec., occurred $2^m\ 48^s$ after the commencement. During the first 4^m, the prevailing period was 4.6 sec. (max. $2a = 0.20$ mm) ; while, during the remainder of this section, it was 8.0 sec. (max. $2a = 0.30$ mm). There were also some traces of slow vibrations.

2nd Preliminary Tremor lasted $7^m\ 41^s$, and began with a well defined vibration of $T=36.4$ sec., whose two displacements were as follows:—

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* A description of this Observatory has been given in the Jour. Sc. Coll., Imp. Univ. Tokyo, Vol. XI.

1st motion...... $a=0.83$ mm, towards W;
2nd „ ......$2a=2.5$ „ , „ E;

The next vibration, which was the maximum in this section, was as follows:—

$T=49.7$ sec.
1st motion......$2a=4.8$ mm, towards W.
2nd „ ......$2a=5.8$ „ , „ E.

Then there followed 2 large decreasing vibrations of $T=54$ sec. The next vibration ($2a=2.27$ mm) was very slow, $T=86$ sec.; there being also some traces of smaller movements. For the next 54 sec., there were 3 displacements as follows:—

1st motion......$2a=4.1$ mm, towards W;
2nd „ ......$2a=4.5$ „ , „ E;
3rd „ ......$2a=2.7$ „ , „ W;

the first 2 displacements constituting a vibration of $T=37.7$ sec. For the next 47.8 sec., the motion was much smaller and nearly uniform:—$2a=0.97$ mm, $T=26.5$ sec.; there being also some small vibrations of $T=9.0$ sec.

Principal Portion. The commencement of the pricipal portion was not well marked, and indicated only by the presence of one and half vibrations of $T=59$ sec., which together lasted $1^m\ 38^s$; the 1st displacement (max.) being $2a=1.3$ mm. These were mixed with small well defined vibrations of $2a=0.33$ mm, $T=11.3$ sec.

For the next $4^m\ 50^s$, there appeared *proper oscillations* of the pendulum of $T=53$ sec.; the range of motion of the first nine displacements, which were specially large, being as follows: 1.96 mm (towards E); 4.4; 6.47; 6.88; 8.68; 9.8; 10.8; 10.7; 6.74 mm. The last displacement of this epoch was 1.94 mm, towards W.

Then the period became shorter, and for the next $1^{m}\ 50^{s},4$, there were 4 well defined vibrations of $T=27.6$ sec.; the very first motion being 4.07 mm, towards E. The 1st displacement of the 3rd vibration, which had a maximum $2a$ of 6.24 mm, occurred $1^{m}\ 0^{s}$ after the commencement of this section.

Thereafter the period again quickened, and for the next $1^{m}\ 7^{s}$, the motion consisted of 4 regular vibrations of $T=16.8$ sec., $2a=2.4$ mm.

For the next $1^{m}\ 22^{s}$, these were 8 well defined vibrations of $T=10.3$ sec., (more or less distinctly grouped into 4 slower movements of $T=20.5$ sec.); the $2a$'s of 1st and 8th vibrations, which were the greatest, being respectively 3.67 and 3.57 mm.

For the next $8^{m}\ 39^{s}$, the motion became much smaller, but remained very nearly constant; and the two gratest vibrations of $2a=1.54$ mm and $2a=1.4$ mm occurred respectively at the commencement and end of this phase; $T=11.3$ sec.

For the next $8^{m}\ 15^{s}$, the motion became again smaller:—

max. $2a=0.8$ mm; $T=11.3$ sec.

For the next $7^{m}\ 42^{s}$, the motion was as follows:—

max. $2a=0.72$ mm; $T=12.8$ sec.

End Portion and W_2 and W_3 Vibrations. The average periods deduced from 7 successive groups, each of 50 vibrations, during the first $80^{m}\ 57^{s}$, were as follows:—

(1)	During 1st	$10^{m}\ 00^{s}$,	$T=12.0$ sec.
(2)	„ next	11 12,	„ 13.4
(3)	„ „	10 52,	„ 13.0
(4)	„ „	11 35,	„ 13.9
(5)	„ „	11 58,	„ 14.3
(6)	„ „	12 00,	„ 14.4
(7)	„ „	13 20,	„ 16.0

For the next $4^m 42^s$, the motion consisted of slow vibrations.

The subsequent portion may be regarded as belonging to the earthquake motion propagated along the *major arc* of the earth between India and Japan, and consisted at first of vibrations of $T=30$ sec., $2a=0.067$ mm; there being also some slower as well as quicker movements. After $9^m 23^s$, the motion became regular and very distinct (marked W_2 in the diagram, Pl. I, the *Publications*, No. 23), and consisted, during the next $6^m 28^s$, of vibrations of $T=24.3$ sec., whose max. $2a$ was 0.13 mm; the movements being larger during the first $3^m 39^s$.

During the next $2^m 38^s$, the motion was smaller; $T=22.1$ sec.

During the next $7^m 5^s$, the motion became again quite distinct:—

$$T=19.4 \text{ sec.}, \quad 2a=0.19 \text{ mm}.$$

Thereafter the motion became smaller, the average periods deduced from 3 successive series, each of 50 vibrations, being as follows:—

(1)	During	1st	$15^m 14^s$,	$T=18.2$ sec.
(2)	„	next	13 55 ,	„ 16.7 „
(3)	„	„	14 00 ,	„ 16.8 „

These vibrations were divided more or less distinctly into a number of successive maxima, which occurred at an average interval of $7^m 30^s$.

Then there followed 3 slight slow vibrations of $T=44$ sec., which may correspond to the W_3 motion, or the repetition of the earthquake first propagated along the *minor arc* of the earth between India and Japan. The succeeding vibrations had an average T of about 20.5 sec.

15. *NS Component at Hongō, Tokyo.* (See Pl. II, the *Publications*, No. 23.) The record was furnished by a long-period

Omori Horizontal Pendulum, whose construction was similar to that of the EW Component apparatus (§14), and whose instrumental constants were as follows :—

Vertical distance between the point of suspension and the point of support = 2.65 metres.
Length of the strut = 1 metre.
Weight of the heavy bob = 46.0 kg.
Multiplication of the pointer = 20.
Oscillation period of the pendulum = 48.5 sec.

1st Preliminary Tremor lasted $7^{m}\,6^{s}$, and began sharply with a slow vibration, whose two displacements were as follows :—

1st motion.... $a=0.17$ mm, towards N;
2nd „ ....$2a=0.28$ „ , „ S;

the vibration being mixed with small movements, whose very 1st displacement was $a=0.07$ mm, towards N.

The motion was larger (max. $2a=0.43$ mm) and nearly constant during the first $4^{m}\,28^{s}$ of this phase, consisting of vibrations as follows :—

For the 1st $2^{m}\,29^{s}$: $T=29.8$ sec.
„ „ next $1^{m}\,59^{s}$: „ $=20.0$ „

During the remaining $2^{m}\,38^{s}$, the motion was small :—

$T=15.8^{sec.}$, $2a=0.22^{mm}$.

Throughout this phase, there were superpositions of small well defined vibrations of $T=5.2$ sec., $2a=0.14$ mm.

2nd Preliminary Tremor lasted about $8^{m}\,20^{s}$. During the first $2^{m}\,0^{s}$, the motion was large and consisted of 3 vibrations made up of the following six displacements :—

(1) $a=0.55$ mm, towards N,
(2) $a=2.33$, „ S, ...$\frac{1}{2}\times T=11.6$ sec.
(3) $2a=3.95$, „ N,
(4) $2a=3.8$, „ S, ... $T=46.2$ sec.

$$\left.\begin{array}{l}(5)\ \ 2a=3.45\text{ mm, towards N,}\\ (6)\ \ 2a=2.73\quad ,\quad „\quad\ \text{S,}\end{array}\right\}\cdots\cdots\cdots\cdots T=46.2\text{ sec.}$$

For the next $2^{m}\,3^{s}$, the motion was small and consisted of 3 vibrations, of which the first had a $T=55.2$ sec., and the last two an average $T=33.5$ sec.; the 2nd vibration having the max. $2a$ of 1.63 mm.

For the next $4^{m}\,22^{s}$, the motion was larger and nearly constant, and consisted of 6 vibrations of $T=43.7$ sec.; the initial motion being $a=1.75$ mm, towards N. The 2nd and 3rd displacements formed a vibration of $T=40.4$ sec.; the 3rd vibration having the max. $2a$ of 3.53 mm.

Principal Portion. The first $1^{m}\,25^{s}$ was made up of 2 slow vibrations of $T=42.5$ sec. The next vibrations was still greater and the recording pointer of the instrument went out of the smoked paper.

$3^{m}\,28^{s}$ later, at $1^{h}\,20^{m}\,19^{s}$, the pointer again entered on the smoked paper; the motion being, for the next 55 sec., greater than 8.3 mm. For the next $4^{m}\,23^{s}$, the diagram showed still large pendulum oscillations, which were nearly constant:—max. $2a=6.65$ mm, $T=47.8$ sec. For the next $1^{m}\,25^{s}$ there were 2 smaller vibrations:—max. $2a=2.7$ mm, $T=42.5$ sec.

For the dext $4^{m}\,27^{s}$, the motion was nearly uniform and consisted essentially of vibrations of $T=10.3$ sec., max. $2a=1.7$ mm; there being also some traces of slower movements of $T=$about 23 sec. For the next $3^{m}\,58^{s}$, the motion consisted of 21 well defined vibrations of $T=11.2$ sec., max. $2a=1.4$ mm. For the next $4^{m}\,57^{s}$, the motion consisted chiefly of the vibrations of $T=19.5$ sec., max. $2a=1.3$ mm; there being, towards the end of this epoch, movements of $T=10.4$ sec., max. $2a=1.2$ mm. For the next $7^{m}\,35^{s}$, the motion was much smaller, but nearly constant:—

$T=10.9$ sec., $2a=0.68$ mm. For the next $10^{m}\ 0^{s}$, the motion was slightly smaller :—$T=22.6$ sec., max. $2a=0.58$ mm.

End Portion and *W_2 Vibrations.* For the first $11^{m}\ 14^{s}$, the motion was nearly constant :—$T=12.5$ sec., max. $2a=0.3$ mm. For the next $33^{m}\ 32^{s}$, the motion was again slightly smaller, but nearly constant, (max. $2a=0.2$ mm), the average period deduced from three successive series of 50 vibrations being as follows :—

$$\left.\begin{array}{l} T=12.9\text{ sec.}\\ 12.7\\ 13.5\end{array}\right\}\ldots\ldots\ldots\textit{Mean, }13.0\text{ sec.}$$

In some places these vibrations were mixed with slower ones of $T=26.2$ sec.

Then, at $2^{h}\ 43^{m}\ 37^{s}$ there appeared three slow vibrations of $T=45$ sec., which lasted together $2^{m}\ 15^{s}$, (max. $2a=0.1$ mm); there being also a superposition of smaller movements of $T=11.9$ sec. These vibrations may belong to the earthquake motion propagated along the *major arc* of the earth. The subsequent vibrations gradually diminished, the period being as follows :—

$$\left\{\begin{array}{llll} \text{for the 1st} & 3^{m}\ 51^{s} & : & T=21.0\text{ sec.}:\\ \text{,, next} & 4\ \ 48 & : & \text{,, }=17.0\text{ ,, };\\ \text{,, ,,} & 7\ \ 25 & : & \text{,, }=19.4\text{ ,, }.\end{array}\right.$$

There were also small vibrations of $T=12.6$ sec.

The distinct commencement of the W_2 motion occurred at $3^{h}\ 21^{m}\ 17.^{s}$ $4^{m}\ 0^{s}$ later on, the motin became larger and well defined, as follows :—

For the 1st $2^{m}\ 45^{s}$:—$T=25.4$ sec., max. $2a=0.1$ mm.

For the next $12^{m}\ 46^{s}$, the motion became quicker, the T during the earlier $8^{m}\ 28^{s}$ being 20.7 sec. During the remaining $4^{m}\ 14^{s}$ of this epoch, which formed the most active part of the

W_2 motion, the T was $=19.5$ sec.; max. $2a$ of 0.12 mm occurring at the commencement.

For the next $5^m\,13^s$, the motion was small:—$T=$about 19.0 sec. For the next $8^m\,42^s$, the motion became again larger:—$T=17.4$ sec., $2a=0.09$ mm. For the next $1^m\,58^s$, the motion was small, T being 16.9 sec. For the next $2^m\,57^s$, the motion was also small, but slower:—$T=29.5$ sec. (?) For the next $6^m\,56^s$, the motion became again active:—$T=20.8$ sec., $2a=0.05$ mm.

The period of the subsequent vibrations was as follows:—

During the 1st $4^m\,46^s$: $T=26.1$ sec.;
„ next 2 32: „ $=16.9$ „ ;
„ „ 22 42: „ $=17.7$ „ ;
„ „ 14 22: „ $=19.6$ „ .

16. ***Vertical Component at Hongō, Tokyō.*** (See Pl. III, the *Publications*, No. 23.) The diagram was furnished by a continuous vertical motion recorder, which is essentially a Gray-Ewing type seismograph, with some modifications for reducing the friction between its different parts. The instrumental constants were as follows:—

Length of the vertical spiral springs $=1.2$ metres.
Horizontal distance between the centre of the steady mass and the pivot $=1.2$ metres.
Weight of the heavy bob $=9$ kg.
Multiplication of the pointer $=12$.
Oscillation Period of the pendulum $=4$ sec.

Preliminary Tremors. For the first $12^m\,16^s$, the motion consisted mostly of pendulum vibrations of $T=4.2$ sec.; the two greatest movements of 0.71 and 0.33 mm occurring 12^s and $9^m\,2^s$ respectively after the commencement. The diagram showed alternations of maximum and minimum groups. At $7^m\,45^s$ from the commencement there were 3 slower vibrations of the following elements :—$T=7.3$ sec., $2a=0.31$ mm.

Thereafter the pendulum oscillations almost disappeared, and for the next $5^m\,22^s$ the motion was very small and slow.

Principal Portion. During the first $3^m\,46^s$ the motion was regular, having the following elements :—$T=45.2$ sec., $2a=0.07$ mm.

For the next $10^m 39^s$, the motion was most active, as follows :—

(*i*) During the 1st $1^m\,29^s$; $T=29.7$ sec., $2a=0.28$ mm.
(*ii*) „ next 1 07 ; „ $=22.3$ „ , „ $=0.13$
(*iii*) „ „ 2 56 ; „ $=14.7$ „ , „ $=0.29$
(*iv*) „ „ 5 09 ; „ $=13.4$ „ , „ $=0.092$.

The maximum movements of (*ii*) and (*iii*) occurred at $1^h\,22^m\,00^s$ and $1^h\,23^m\,07^s$, respectively.

End Portion. The motion was small and as follows :—

During the 1st $6^m\,12^s$; $T=11.6$ sec.
„ next 2 42 ; „ $=18.0$ „
„ „ 2 32 ; „ $=15.2$ „
„ „ 11 17 ; „ $=14.4$ „

Thereafter the motion gradually decreased, being reduced almost to *nil* in the course of the next 30 minutes. Towards the end :— $T=15.4$ sec.

W_2 Motion. At $3^h\,33^m\,22^s$, there appeared some slight movements. After $4^m\,9^s$, the motion became distinct, the average T during the next $3^m\,15^s$ being 19.5 sec. This probably indicates the 3rd phase of the principal portion of the W_2 motion.

17. *Summary of the Hongō (Tokyo) Observations.*

For the sake of convenience I give below tabular statements of the results of analysis contained in the preceding §§; the numerals enclosed within brackets show the order of occurrence of different subdivisions in each phase of motion.

TABLE IV. *EW Component at Hongō.*

Duration.	$T=$ Average Period.	Max. $2a$.
[1st Preliminary Tremor. Duration $=7^{m}\ 17^{s}$.]		
(1) $4^{m}\ 00^{s}$	4.6 sec. 24.7	0.20 mm 0.57
(2) 3 17	8.0	0.30
[2nd Preliminary Tremor. Duration $=7^{m}\ 41^{s}$.]		
(1) $0^{m}\ 36.4^{s}$	36.4 sec.	2.5 mm
(2) 0 49.7	49.7	5.8
(3) 1 48.0	54.0	
(4) 1 26	86.0	2.27
(5) 0 54	37.7	4.50
(6) 0 47.8	26.5 9.0	0.97 Small.
[Principal Portion. Duration $=35^{m}\ 23^{s}$.]		
(1) $1^{m}\ 38^{s}$	59.0 sec. 11.3	1.30 mm 0.33
(2) 4 50	53.0	10.8 (pendulum oscillations)
(3) 1 50	27.6	6.24
(4) 1 7	16.8	2.4
(5) 1 22	10.3 20.5	3.67 —
(6) 8 39	11.3	1.54
(7) 8 15	11.3	0.80
(8) 7 42	12.8	0.72
[End Portion.]		
(1) $80^{m}\ 57^{s}$	13.6 sec.	Small.
(2) 4 42	—	„

Duration.	$T=\begin{cases}\text{Average}\\ \text{Period.}\end{cases}$	Max. $2a$.
	[W_2 Motion.]	
(1) 9^{m} 23^{s}	30.0 sec.	0.067 mm
(2) 6 28	24.3	0.13
(3) 2 38	22.1	Small.
(4) 7 5	19.4	0.19
(5) 43 9	17.2	Small.
	[W_3 Motion.]	
(1) 2^{m} 12^{s}	44.0	Small.
(2) ——	20.5	„

TABLE V. *NS Component at Hongō.*

[1st Preliminary Tremor. Duration $\doteq 7^{m}\ 6^{s}$.]		
(1) 2^{m} 29^{s}	29.8 sec.	......0.43 mm
(2) 1 59	20.0	
(3) 2 38	15.8	0.22
Mixed throughout	5.2	0.14
[2nd Preliminary Tremor. Duration $= 8^{m}\ 20^{s}$.]		
(1) 2^{m} 0^{s}	23.1 sec.	........2.33 mm
	46.2	........3.95
(2) 2 3	55.2	.... —
	33.5	........1.63
(3) 4 22	40.4	........3.53
	44.4	

Duration.	$T=$ Average Period.	Max. $2a$.
	[Principal Portion. Duration = $42^m\ 33^s$.]	
(1) $1^m\ 25^s$	42.5 sec.	
(2) 4 23	(Motion large, pointer went out.)	
(3) 4 23	47.8 (pend. oscil.)	6.65
(4) 1 25	42.5	2.7
(5) 4 27	10.3 .... 23.	1.7
(6) 3 58	11.2	1.4
(7) 4 57	19.5 .... 10.4	1.3 1.2
(8) 7 35	10.9	0.68
(9) 10 00	22.6	0.58
	[End Portion.]	
(1) $11^m 14^s$	12.5 sec	0.3 mm
(2) 33 32	13.0 .... 26.2	0.2
	[W_2 Motion.]	
(1) $2^m\ 15^s$	45.0 sec. 11.9	0.1 mm —
(2) 16 4	19.1 12.6	(Small.)
(3) 19 21	—	(Small.)
(4) 4 0	—	„
(5) 2 45	25.4	0.1
(6) 8 28	20.7	
(7) 4 14	19.5	0.12
(8) 5 13	19.0	(Small.)
(9) 8 42	17.4	0.09

Duration.	$T=\left\{\begin{array}{l}\text{Average}\\\text{Period.}\end{array}\right.$	Max. $2a$.
	[W_2 Motion.]	
(10) 1 58	16.9	(Small.)
(11) 2 57	29.5	„
(12) 6 56	20.8	0.05
(13) 4 46	26.1	(Small.)
(14) 39 36	18.1	„

TABLE VI. *Vertical Component at Hongō.*

	[Preliminary Tremors.]	
(1) 12^m 16^s	4.2 sec. (pend. oscil.) 7.3	0.71 mm 0.31
(2) 5 22	—	(Small.)
	[Principal Portion.]	
(1) 3^m 46^s	45.2 sec.	0.07 mm
(2) 1 29	29.7	0.28
(3) 1 07	22.3	0.13
(4) 2 56	15.7	0.29
(5) 5 09	13.4	0.092
	[End Portion.]	
(1) 6^m 12^s	11.6 sec.	(Small.)
(2) 16 31	15.9	„
(3) 30	15.4	„
	[W_2 Motion] Commencement at 3^h 33^m 22^s	
(1) 4^m 09^s	—	(Small.)
(2) 3 15	19.5 sec	„

18. ***EW Component at Hitotsubashi, Tōkyo.*** The diagram was furnished by Omori Horizontal Pendulum of portable form, whose instrumental constants were as follows:—

Vertical distance between the point of suspension and the point of support = 0.75 metre.
Length of strut = 0.75 metre.
Weight of the heavy bob = 6.4 kg.
Multiplication of the pointer = 8.
Oscillation period of the pendulum = 31.1 sec.

At Hitotsubashi, the ground is low and very soft.

1st Preliminary Tremor. Duration $= 7^m\ 32^s$. The motion was very nearly constant in amplitude:—$T = 4.6$ sec., $2a = 0.44$ mm.; there being also ill-defined traces of two sets of slower movements of $T =$ about 7.2 and 15.7 sec., respectively.

During the earlier one-third of this phase, the motion was mixed up with very small movements of the *macro-seismic character*, of $T = 0.71$ sec.

19. *Tromometer Records.* The earthquake was also recorded by two Omori Horizontal Pendulum Tromometers* set up at the Seismological Institute (Hongō) and at the Central Meteorological Observatory; the two instruments, whose magnifications were 120 and 87 times respectively, being in other respects exactly similar to one another, as follows:—

Weight of the heavy bob = 50 kg.
Vertical distance between the point of support and the point of suspension = 1 metre.
Length of the strut = 20 cm.
Total length between the point of support and the writing index = 120 cm.

The natural oscillation period of the pendulums at the Seismological

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* These instruments are described in the *Publications*, No. 12.

Institute and the Central Meteorological Observatory were respectively 21 and 10 sec.

20. ***EW Component at Hongō, Tokyo, registered by Tromometer.***

1st Preliminary Tremor, Duration $=7^{m}\,27^{s}$. The commencement was well defined, the very first vibration being as follows :—

1st displacement : $a=0.017$ mm, towards W ;
2nd ,, : $2a=0.038$, ,, E .

For the first 10.6 sec., during which there were $2\frac{1}{4}$ vibrations, the motion was small. Then took place a distinctly larger movement towards E.

The subsequent motion remained on the whole nearly constant, and consisted of the following two sets of fundamental vibrations, (*i*) and (*ii*), one mixed between the other :—

(*i*) $T=8.6$ sec., $2a=0.33$ mm ;
(*ii*) ,, $=4.4$,, , ,, $=0.25$,, .

The periods of vibrations belonging to these two groups, deduced from different portions of this section were as follows :—

(*i*)	$T=8.5$ sec.	(deduced from 9 vibr.) ;	$2a=0.28$ mm ;
	,, $=8.5$,,	(,, 10) ;	,, $=0.33$,, ;
	,, $=8.6$,,	(,, 11) ;	,, $=0.20$,, ;
	,, $=8.8$,,	(,, 4) ;	,, = — ,, .
(*ii*)	$T=4.3$ sec.	(deduced from 10 vibr.) ;	$2a=$ — mm ;
	,, $=4.3$,,	(,, 8) ;	,, $=0.18$,, ;
	,, $=4.5$,,	(,, 10) ;	,, $=0.25$,, ;
	,, $=4.6$,,	(,, 15) ;	,, $=0.14$,, .

Throughout this phase, there were also smaller movements of $T=2.2$ sec.

2nd Preliminary Tremor. Duration $=7^{m}\,21^{s}$. The motion began with the following 2 vibrations :—

1st vibr.:—$T=12.1$ sec. ..... 1st motion, $a=0.33$ mm, towards E;
2nd „ $2a=0.83$ „ „ W.

2nd vibr.:—$T=10.3$ „ .... 1st motion, $2a=1.05$ mm, towards E;
2nd „ $2a=0.66$ „ „ W.

For the next $2^m 23^s$, the motion gradually decreased and consisted of vibrations of $T=9.4$ sec., mixed up with others of $T=4.7$ sec., $2a=0.21$ mm.

Then took place suddenly the 2nd large vibration:—

$T=13.5$ sec. .... 1st motion, $2a=0.88$ mm, towards W;
2nd „ , $2a=1.03$, „ E.

For the next $1^m 20^s$, the motion was again small and consisted of 2 sets of vibrations of $T=12.1$ and 4.9 sec., respectively.

Then took place suddently the 3rd large vibration:—

$T=11.0$ sec. .... 1st motion, $2a=0.90$ mm, towards W;
2nd „ , $2a=0.70$, „ E.

During the remaining $2^m 51^s$, the motion was small and consisted of the following 2 sets of vibrations:—

(*i*) $T=8.2$ sec.; $2a=0.61$ mm;
(*ii*) „ $=4.7$; „ $=$Small.

1st and 2nd Phases, Principal Portion. Duration$=7^m 21^s$. The commencement was not well marked, except for the appearance of some slow movements. During the first $3^m 3^s$, the motion consisted of 3 sets, as follows:—

(*i*) $T=9.4$ sec., $2a=0.40$ mm;
(*ii*) „ $=16.8$ „ , „ $=0.53$ „ ; (pend. oscil. ?)
(*iii*) „ $=53.0$ „ , „ $=0.36$ „ .

The remaining $4^m 18^s$ was made up of the following large vibrations:—

(*i*) During the 1st $1^m 56^s$: 4 vibrations of $T=29.0$ sec.;
$2a=0.66$ mm (last but two vibr.).
(*ii*) During the next $2^m 27^s$: 4 vibrations of $T=38.5$ sec.;
$2a=0.58$ mm.

In the last $3^m 17^s$ of this phase, the motion remained very nearly constant in amplitude; there being also vibrations of $T=9.1$ sec., $2a=0.25$ mm.

3rd Phase, Principal Portion. Duration, about $9^m 40^s$. The motion began with a sudden large displacement of $a=0.97$ mm, towards W. The counter motion, towards E, was still larger, and the recording pointer strack against the side supports, the vibrations remaining active throughout this phase.

The principal vibrations had an average T of 34.8 sec., the amplitude being very large. There were also large movements of $T=21$ sec., which were probably due to pendulum oscillations.

4th, etc. Phases, Principal Portion. The motion became quicker in period, the amplitude remaining on the whole nearly constant for the next $11^m 36^s$:—

(i) At the commencement:—$T=12.6$ sec., $2a=1.67$ mm.
(ii) Towards the end:—$T=12.0$ sec., $2a=1.25$ mm.

The motion consisted of a series of alternations of maximum and minimum groups of vibrations; each maximum group beginning with a sudden displacement towards E, followed by a much larger counter motion towards W, as shown below:—

	Motion towards E.		***Motion towards W.***	
1st Group.	1st displacement,..	0.17 mm;	2nd displacement,..	0.21 mm;
	3rd „	0.61 ;	4th „	1.18 ;
	5th „	1.41 ;	6th „	1.09 ;
	7th „	0.72 .		

2nd Group.
1st displacement,..0.22 mm ; 2nd displacement,..0.40 mm ;
3rd „ 0.57 ; 4th „ 1.05 ;
5th „ 1.28 ; 6th „ 1.08 ;
7th „ 1.03 .

3rd Group.
1st displacement,..0.76 mm ; 2nd displacement,..1.53 mm ;
3rd „ 1.67 ; (Pointer ran out)

4th Group.
1st displacement,..0.14 mm ; 2nd displacement,..0.32 mm ;
3rd „ 0.68 ; 4th „ 0.97 ;
5th „ 0.92 ; 6th „ 0.77 .

In the minimum groups, there were also quicker vibrations :—$T=8.2$ sec., $2a=0.24$ mm.

For the next $6^m\ 54^s$, the motion became much smaller :— $T=11.8$ sec., $2a=0.58$ mm.

Thereafter the motion became again abruptly much smaller.

Pulsatory Oscillations. On April 4th, there existed slight but distinct pulsatory oscillations, whose elements of motion, before and after the earthquake, were as follows :—

Before the eqke : $T=4.1$ sec., $2a=0.012$ mm.
After the eqke : „ $=4.1$ „ , „ $=0.011$ „ .

The result of the analysis given above are summarized in the following table :—

TABLE VII. *EW Tromometer Record at Hongō.*

Duration.	$T=\begin{cases}\text{Average}\\\text{Period.}\end{cases}$	Max. $2a$.
	[1st Preliminary Tremor. Duration $=7^m\ 27^s$]	
	8.6 sec. 4.4 2.2	0.33 mm 0.25 (Small.)

Duration	$T=\left\{\begin{array}{l}\text{Average}\\ \text{Period.}\end{array}\right.$	Max. $2a$.
[2nd Preliminary Tremor. Duration $=7^m\ 21^s$]		
	11.8 sec.	1.05 mm
	8.8	0.61
	4.8	0.21
[1st and 2nd Phases, Principal Portion. Duration $=7^m\ 21^s$]		
(1) $3^m\ 3^s$	9.4 sec.	0.40 mm
	16.8	0.53
	53.0 (?)	0.36
(2) 1 56	29.0	0.66
(3) 2 27	38.5	0.58
In (2) and (3)	9.1	0.25
[3rd Phase, Principal Portion. Duration $=9^m\ 40^s$].		
	34.8 sec.	(Large.)
	21.0 (pend. oscil.)	„
[4th, etc. Phases, Principal Portion.]		
(1) $11^m\ 36^s$.	12.3 sec.	1.67 mm
	8.2	0.24
(2) 6 54	11.8	0.58

21. ***Tromometer Record obtained at the Central Meteorological Observatory, Tōkyo.*** The record is very imperfect, as the natural oscillation period of the pendulum was too short.

1st Preliminary Tremor. Duration $=7^m\ 30^s$. The motion, which was much smaller during the last $3^m\ 12^s$ of this phase, consisted of the following two sets of vibrations :—(*i*) $T=4.4$ sec., $2a=0.17$ mm ; (*ii*) $T=7.4$ sec., $2a=0.22$ mm.

2nd Preliminary Tremor. Duration $=7^m\ 23^s$. The motion was much greater than in the preceding phase, and consisted of large pendulum oscillations of $T=9.1$ sec., whose maximum vibration ($2a=1.06$ mm) was the 6th in the maximum group occurring at the commencement. There were also some doubtful traces of slow vibrations.

1st and 2nd Phases, Principal Portion. Duration $=7^m\ 17^s$. There were more or less definite traces of slow vibrations:—$T=36.8$ sec., $2a=0.20$ mm, these being mixed with pendulum oscillations of $T=8.1$ sec. (max. $2a=0.23$ mm).

3rd Phase, Principal Portion. Duration $=8^m\ 0^s$. For the first $2^m\ 9^s$, the motion was comparatively small, and made up of two slow vibrations of $T=23.8$ sec., followed by pendulum oscillations of $T=9{,}0$ sec. (max. $2a=1.4$ mm). During the remaining part of this phase, the pendulum oscillation attained its full activity (max. $2a=2.9$ mm); $T=11.0$ sec.

4th, etc. Phases, Principal Portion. The motion became smaller, and consisted during the next $4^m\ 49^s$ of the following vibrations:—$T=10.3$ sec., $2a=2.2$ mm; the vibrations being divided into 3 successive maximum groups, which occurred at an average interval of $1^m\ 36^s$. There were also some slower movements of $T=$about 15.2 sec. (max. $2a=0.78$ mm).

Then the motion became much smaller and remained nearly constant for the next $6^m\ 2^s$:—$T=11.6$ sec., $2a=0.48$ mm. During the next $7^m\ 36^s$, the motion was again smaller:—$T=11.4$ sec. $2a=0.12$ mm. Thereafter the motion became still smaller.

Pulsatory Oscillations. The average period of the pulsatory oscillations, measured after the earthquake, was 4.14 sec.

22. ***Ōsaka, Japan. EW Component.*** (See Pl. VI, the

Publications, No. 23.) The Meteorological Observatory (Director, N. Shimono).

The record was given by an Omori Horizontal Pendulum of portable form, of the following constants:—

Vertical distance between the points of suspension and of support $= 86$ cm.
Length of the horizontal strut $= 44$ cm.
Weight of the heavy bob $= 16$ kg.
Multiplication of the pointer $= 20$
Oscillation period of the pendulum $= 28$ sec.

The Ōsaka Observatory is situated on low soft ground, about 5.3 m above the sea-level.

Time of earthquake occurrence $= 0^h\ 58^m\ 51^s$. Duration $= 3\frac{1}{2}^h$.

1st Preliminary Tremor. Duration $= 7^m\ 12^s$. The motion began with quick vibrations of gradually increasing amplitude, and after 20 sec. there appeared the first slow vibration consisting of the following 2 displacements:—

1st motion, $a = 0.37$ mm, towards W (marked *b* in the diagram);
2nd „ , $2a = 0.70$ „ , „ E.

During the first $4^m\ 0^s$ of this phase the motion consisted of the following 3 sets of vibrations;—

(*i*) $T = 23.8$ sec., $2a = 1.05$ mm; (*iii*) $T = 8.5$ sec., (small);
(*ii*) „ $= 4.7$ „ , „ $= 0.53$ „ ;

there being also traces of still quicker movements.

During the remaining $3^m\ 12^s$, the motion was much smaller, the vibrations being two-fold, as follows:—

(*i*) $T = 4.5$ sec., $2a = 0.22$ mm; (*ii*) $T = 7.8$ sec., $2a =$ small.

2nd Preliminary Tremor. Duration $= 6^m\ 55^s$. The 1st 2 vibrations consisted of the following 4 displacements (marked *hi, ji, jk, kl* in the diagram):—

$$\text{1st vibr.}\left\{\begin{array}{llll}\text{1st motion,} & a=0.49\text{ mm,} & \text{towards} & \text{W,}\\ \text{2nd}\quad ,, & 2a=1.58\ ,,\ , & ,, & \text{E,}\end{array}\right\}\cdots\tfrac{1}{2}\times T=10.1\text{ sec.,}$$

$$\text{2nd vibr.}\left\{\begin{array}{llll}\text{1st}\quad ,, & 2a=2.32\ ,,\ , & ,, & \text{W,}\\ \text{2nd}\quad ,, & 2a=2.53\ ,,\ , & ,, & \text{E,}\end{array}\right\}\cdots\cdots T=32.5\ ,,\ ;$$

the latter vibration being the maximum motion. During the rest of this phase, the greatest vibration (marked *pq*) was the following:—$T=25.5$ sec., $2a=1.69$ mm. 2 other vibrations marked *rs* and *st* had a mean period of 30 sec.; the subsequent portion being much confused by the proper pendulum oscillations.

Principal Portion. [*1st and 2nd phases*]: Duration$=6^{m}\,54^{s}$. For the 1st $3^{m}\,55^{s}$, the motion was small:—$T=21.7$ sec., $2a=1.58$ mm. For the next $3^{m}\,18^{s}$, the diagram consisted of the proper pendulum oscillations, as follows:—$T=28.3$ sec., $2a=4.5$ mm. [*3rd phase*]: Duration$=9^{m}\,56^{s}$. For the 1st $4^{m}\,38^{s}$, the pendulum oscillations were very active:—$T=26.8$ sec., $2a=11.7$ mm. Thereafter the motion became quieter and remained nearly constant for the next $5^{m}\,15^{s}$:—$T=24.2$ sec., $2a=2.25$ mm; there being also small vibrations of $T=11.3$ sec. [*4th phase*]: Duration$=8^{m}\,0^{s}$. $T=22.2$ sec., $2a$ being smaller than 0.95 mm, except one vibration whose $2a$ was 1.73 mm. There were some superposed vibrations of $T=$about 10.5 sec. [*5th phase*]: Duration$=10^{m}\,29^{s}$. The motion consisted of the following 3 sets of vibrations:—

$$\left\{\begin{array}{ll}(i) & T=14.4\text{ sec., } 2a=0.63\text{ mm};\\ (ii) & ,,=18.5\ ,,\ ,\ ,,=0.68\ ,,\ ;\\ (iii) & ,,=10.2\ ,,\ ,\ \text{(small).}\end{array}\right.$$

End Portion. During the 1st $7^{m}\,42^{s}$, the motion was on the whole constant, and consisted of well defined vibrations of $T=14.3$ sec., $2a=0.22$ mm. For the next $13^{m}\,2^{s}$, the motion consisted of the following two sets of vibrations:—(*i*) $T=10.8$ sec., $2a=0.14$ mm; (*ii*) $T=21.7$ sec., (small).

Thereafter the motion decreased gradually and was brought almost to *nil* in the course of the next 30 min.; the period deduced from 3 successive series, each of 50 vibrations, being as follows:—

$$\left.\begin{array}{l} T=14.3 \text{ sec.} \\ \quad\;\; 13.7 \\ \quad\;\; 14.3 \end{array}\right\} \textit{mean}, \ 14.1 \text{ sec.}$$

W_2 Motion. At $3^h\,22^m\,30^s$, there appeared some slow movements which for the 1st $1^m\,20^s$ remained indistinct. During the next $5^m\,26^s$, the motion was still small, but consisted of regular vibrations of $T=25.1$ sec. For the next $5^m\,53^s$, the motion, which was slightly larger, became decidedly quicker:—$T=20.8$ sec. During the next $3^m\,0^s$, the period remained unchanged, but the motion became markedly larger:—$T=20.0$ sec., $2a=0.02$ mm. For the next $1^m\,31^s$, the motion was small; $T=$about 18.2 sec. (?). For the next $5^m\,56^s$, the motion was most active:—$T=18.7$ sec., $2a=0.06$ mm; the maximum having occurred at $3^h\,40^m\,56^s$, or $18^m\,26^s$ after the assumed commencement of the W_2 motion. For the next 5^m the motion was more or less distinct.

W_3 Motion. What may correspond to the W_3 motion appeared at $4^h\,34^m\,59^s$, the vibrations being as follows:—$T=18.5$ sec., $2a=0.015$ mm.

23. ***Kobe,*** Japan. ***NS Component.*** (See Pl. VII, the *Publications,* No. 23.) The Meteorological Observatory (Director, G. Nakagawa).

The record was furnished by an Omori Horizontal Pendulum of portable form, whose instrumental constants were as follows:—

Vertical distance between the points of suspension and of support$=90$ cm.

Length of the horizontal strut = 75 cm.
Weight of the heavy bob = 11 kg.
Multiplication of the pointer = 20.
Oscillation period of the pendulum = 27 sec.

The Observatory of Kobe stands on the top of a hill spur 58 m above the sea-level.

The time of earthquake occurrence = 0^h 58^m 26^s.

1st Preliminary Tremor. Duration = 7^m 0^s. The motion consisted of small but distinct vibrations of T=4.4 sec., $2a$=0.05 mm; there being at first some traces of smaller movements. There were also vibrations of T=11.5 sec.

2nd Preliminary Tremor. Duration = 5^m 44^s (?). For the first 17 sec., the motion was small, there being an initial northward slow motion mixed with smaller vibrations. Then took place, for the next 62 sec., two large vibrations of T=31 sec. (pendulum oscillations ?), whose successive displacements were as follows :—

1st motion = 1.3 mm, towards S; 2nd motion = 2.6 mm, towards N.
3rd „ = 2.3 „ , „ S; 4th „ = 1.5 „ , „ N.

For the next 2^m 38^s, the motion was small and consisted of slow irregular vibrations, mixed with small ones. For the next 1^m 58^s, the motion consisted of 4 pendulum oscillations of T= 29.5 sec.; the 2nd having the max. $2a$ of 3.0 mm.

Principal Portion. For the first 2^m 16^s, the motion was small :—T=34 sec., $2a$=0.48 mm. For the next 1^m 59^s, the motion was larger and consisted of 2 and half slow vibrations :—T= 55.8 sec., $2a$=2.0 mm. For the next 2^m 2^s, which may correspond to the 2nd phase, the motion became larger and consisted of 3 vibrations :—T=40.3 sec., $2a$=4.8 mm; the last vibration being the maximum. For the next 1^m 39^s, the record consisted of 3 and half large pendulum oscillations :—$T=28.3$ sec., $2a=8.2$ mm. For the next 4^m 30^s, the motion became smaller, but was still active :—$T=32.0$ sec., $2a=2.7$ mm ; $T=18.5$ sec., $2a=2.0$ mm. For the next 9^m 12^s, the motion was smaller and nearly constant :—$T=23.5$ sec., $2a=1.1$ mm ; $T=9.4$ sec. For the next 8^m 15^s, the motion was again smaller and nearly constant :—$T=11.9$ sec., $2a=0.19$ mm ; $T=17.8$ sec., $2a=0.45$ mm.

Thereafter the motion was much smaller, the T deduced from 3 successive series, each of 50 vibrations, being as follows :—

$$\left.\begin{array}{l} 12.9 \text{ sec.} \\ 13.0 \text{ ,,} \\ 13.4 \text{ ,,} \end{array}\right\} \textit{mean}, \ 13.1 \text{ sec.}$$

24. ***Tadotsu,*** Japan. ***EW Component.*** The Meteorological Observatory (Director, N. Maeda).

The record was furnished by an Omori Horizontal Pendulum of portable form, whose instrumental constants were as follows :—

Vertical distance between the points of suspension and of support = 85 cm.
Length of the horizontal strut = 75 cm.
Weight of the heavy bob = 10 kg.
Multiplication of the pointer = 20.
Oscillation period of the pendulum. = 28 sec.

The Tadotsu Observatory stands on low ground, about 5.9 m above the sea-level, and only 18 m from the sea beach.

Time of earthquake commencement = 0^h 58^m 49^s. Duration = $3\frac{1}{2}^h$.

The record is not very satisfactory owing to a great amount of friction in the seimograph.

1st Preliminary Tremor. Duration = 7^m 0^s. The motion consisted essentially of the P_1 vibrations, mixed with two sets of slower movements, as follows:—$T=4.7$ sec.; $T=10.4$ sec. (?); $T=24.2$ sec., $2a=0.2$ mm (pend. oscil ?). In the latter half of this portion, the motion was very small.

2nd Preliminary Tremor. Duration $=7^{m}\ 42^{s}$. The motion was greater during the first $3^{m}\ 48^{s}$, and the two maximum $2a$'s of 0.86 and 0.62 mm occurred at the commencement and the end of this epoch:—$T=31.5$ sec. During the remaining $3^{m}\ 54^{s}$, the motion was much smaller:—$T=35.6$ sec., $2a=0.14$ mm; $T=14.8$ sec.

Principal Portion. [*1st and 2nd phases.*] Duration $=5^{m}\ 21^{s}$. During the first 52 sec., the motion was small. Then the motion became larger and consisted of slow vibrations:—$T=39.4$ sec., $2a=1.4$ mm; $T=19$ sec.

[*3rd phase.*] Duration, about $6^{m}\ 30^{s}$. The record consisted of large pendulum oscillations (max. $2a>12.4$ mm) of $T=28$ sec.; the pointer having finally got out of the smoked paper.

For the next 6 m, the motion was much smaller and nearly constant:—$T=10.2$ sec., $2a=0.53$ mm; $T=19.7$ sec., $2a=0.72$ mm. Thereafter the motion became again smaller and very gradually diminished, the motion being as follows:—

for the 1st $9^{m}\ 28^{s}$: $T=12.6$ sec., $2a=0.27$ mm;
„ next 15 10 : „ $=13.8$ „ , „ $=0.18$ „ ;
towards the end : „ $=14.3$ „ , „ = Small.

These three sets of vibrations give an average period of 13.6 sec.

W_2 Motion. For about 50 min. before the commencement of the W_2 motion, the vibrations were practically *nil.* Time of commencement of $W_2=3^{h}\ 31^{m}\ 22^{s}$. For the first $5^{m}\ 13^{s}$, the motion was very small, the earlier part being doubtful. For the next

$12^{m}\ 25^{s}$, the motion was small, but distinct:—$T=19.5$ sec., $2a=0.045$ mm.

W_3 Motion. Time of commencement $=4^{h}\ 24^{m}\ 35^{s}$. The motion, indicated for about 3 minutes, consisted of very slight doubtful traces of slow movements of $T=36.3$ sec. (?)

25. ***Taihoku,*** Formosa, Japan. ***EW Component.*** The Meteorological Observatory (Director, H. Kondō).

The record was furnished by an Omori Horizontal Pendulum of portable form, of the following constants:—

Vertical height between the points of suspension and of support $=75$ cm.
Length of the horizontal strut $=75$ cm.
Weight of the heavy bob $=6\frac{1}{2}$ kg.
Multiplication of the pointer $=10$.
Oscillation period of the pendulum $=$ about 14 sec.

The Observatory is situated on soft flat ground, about 9 m above the sea-level.

The motion was recorded evidently with a large amount of friction.

1st Preliminary Tremor. Duration $=6^{m}\ 6^{s}$. During the first $3^{m}\ 30^{s}$, the motion consisted of the vibrations of $T=4.3$ sec., $2a=0.06$ mm, mixed at first with small macro-seismic movements of $T=1.07$ sec.; $T=2.1$ sec. During the remaining $2^{m}\ 36^{s}$, the motion was much smaller and consisted of uniform vibrations of $T=3.3$ sec.

2nd Preliminary Tremor. Duration $=5^{m}\ 25^{s}$. The motion consisted essentially of the vibrations of $T=4.5$ sec., $2a=0.1$ mm. At the commencement and end of this phase, however, there were slower vibrations of $T=21$ sec., $2a=0.1$ mm.

T=about 4.5 sec. [*3rd phase.*] Duration=5^m 40^s. During the first 1^m 44^s, which formed the maximum group, the motion was as follows:—T=9.0 sec., $2a$=12.8 mm; the maximum motion having occurred 1^m 30^s after the commencement of this phase. In the subsequent part, the motion was much smaller:—T=8.9 sec., $2a$=6.3 mm; T=5.0 sec., $2a$=0.33 mm; T=14.8 sec., $2a$=6.3 mm. The vibrations of the last sort were probably due to the proper pendulum oscillations. During the remaining 3^m 5^s of the principal portion, the motion was nearly uniform:—T=8.4 sec., $2a$=1.2 mm; $T\mp$22.3 sec.

End Portion. For the first 5^m 40^s, the motion was nearly constant:—T=8.8 sec., $2a$=0.5 mm; T=5.3 sec.; T=4.0 sec.; there being also some traces of slow vibrations. The subsequent motion became again smaller:—

T= 8.9 sec., $2a$=0.2 mm;
T= 6.4 „ , $2a$=0.17 „ ;
T=13.6 „ , $2a$=0.17 „ .

Towards the very end:—T=10.5 sec.

27. *Tainan,* Formosa, Japan. ***EW Component.*** (See Pl. VIII, the *Publications*, No. 23.) The Meteorological Observatory (Director, T. Endo).

The record was furnished by an Omori Horizontal Pendulum of small multiplication, exactly similar to the one in use at Taichu (§ 26), the only difference being that the Tainan instrument had a natural oscillation period of 17 sec. The observatory stands on low ground about 14 m above the sea-level.

1st Preliminary Tremor. Duration=6^m 15^s. The motion consisted essentially of the following vibrations:—T=4.0 sec., $2a$=0.12 mm. After 1^m 49^s from the commencement, there appeared the superposition of the following slow movements of $T=13.8$ sec., $2a=0.08$ mm.

2nd Preliminary Tremor; 1st and 2nd Phases of Principal Portion. Total duration $=9^m\ 46^s$. During the first $6^m\ 27^s$, the motion was smaller:—$T=12.1$ sec., $2a=2.3$ mm; there being at minimum epochs also some small vibrations. The 2nd preliminary tremor, which was markedly larger than the 1st preliminary tremor, began with a vibration whose two displacements were as follows:—

$$\begin{cases} \text{1st displacement,} & a=0.73 \text{ mm, towards E;} \\ \text{2nd} \quad " & ,\ 2a=1.00 \text{ " , " W.} \end{cases}$$

During the remaining part, the motion became gradually larger:—$T=11.8$ sec., $2a=4.6$ mm; $T=15.3$ sec. (pendulum oscillations ?)

3rd Phase of Principal Portion. The motion was very active during the first $3^m\ 8^s$:—$T=11.8$ sec., $2a=13.8$ mm; the maximum having occurred $0^m\ 45^s$ after the commencement of this phase. For the next $6^m\ 2^s$ the motion was nearly constant:—$T=12.0$ sec., $2a=6.8$ mm. For the next $23^m\ 48^s$, the motion remained also active:—$T=13.2$ sec., $2a=5.6$ mm. Thereafter the motion became much smaller:—$T=12.7$ sec., $2a=0.67$ mm. The motion was indicated till $3^h\ 50^m$ when the smoked paper was changed.

28. ***O'Gyalla,*** (near Budapest), Austria-Hungary. Royal Meteorological and Geodynamic Observatory. (Director, N. Thege v. Konkoly jr.; Assistant, A. Réthly.)

The earthquake was recorded by a pair of Omori Horizontal Pendulums, whose oscillation period was about 15 sec.; the NS component motion being much greater than the EW.

(NS) In the 2nd preliminary tremor, the motion was as follows :—$T=8.4$ sec., $2a=0.4$ mm ; $T=17.2$ sec., $2a=1.4$ mm (pend. oscillations). The max. $2a=2.7$ mm ($T=19.8$ sec.) occurred 22^m 50^s after the commencement of the earthquake, the motion remaining active for the next 10 m.

29. ***Birmingham,*** England. ***EW Component.*** (See Pl. X, the *Publications*, No. 23.)

The observation was made by Dr. C. Davison* with an Omori Horizontal Pendulum, whose instrumental constants were as follows :—

Vertical distance between the point of suspension and the point of support$=0.85$ metre.
Horizontal distance between the point of support and the centre of the heavy bob$=0.70$ metre.
Weight of the mass$=9$ kg.
Multiplication-ratio of the writing-index$=14.4$.
Oscillation period of the pendulum$=34$ sec.
Velocity of recording paper$=10.8$ mm per sec.

Time of commencement$=1^h\ 0^m\ 35^s$. Total Duration$=2^h\ 40^m$.

1st Preliminary Tremor. Duration$=8^m\ 21^s$:—$T=12.0$ sec., $2a=0.035$ mm ; $T=4.6$ sec. ; $T=7.1$ sec.

2nd Preliminary Tremor began at $1^h 8^m 56^s$. Duration$=7^m 37^s$:—$T=15.5$ sec., $2a=0.083$ mm; $T=4.6$ sec., $T=9.7$ sec., $2a=0.028$mm.

Principal Portion began at $1^h\ 16^m\ 33^s$. [*1st and 2nd phases.*] Duration$=8^m\ 49^s$. During the first $6^m 39^s$, the motion was small :—$T=9.9$ sec., $2a=0.07$ mm ; $T=18.8$ sec., $2a=0.16$ mm. During the remaining $2^m\ 10^s$, the motion became larger and consisted of 3½ nearly equal vibrations :—$T=36.6$ sec., $2a=0.24$ mm ; $T=7.5$

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* An account of the seismogram is given by Dr. Davison in the Boll. d. Soc. Sism Italiana, Vol. X.

sec. [*3rd phase.*] Commencement $=1^h\ 25^m\ 22^s$. Duration $=9^m 30^s$. During the first $2^m\ 37^s$, there was a gradually increasing series of 5 vibrations, due to the proper pendulum motion:—$T=31.4$ sec., $2a=2.03$ mm, the greatest being the 4th vibration. For the next $4^m\ 3^s$, the motion was small:—$T=18.7$ sec., $2a=0.73$ mm. For the remaining $2^m\ 51^s$, the motion was larger and regular:—$T=17.1$ sec., $2a=1.56$ mm. [*4th phase.*] Commencement $=1^h\ 34^m\ 52^s$. Duration $=6^m\ 21^s$. The motion was small:—$T=12.3$ sec., $2a=0.60$ mm.

For the next $10^m 30^s$, the motion remained nearly constant:—$T=14.7$ sec., $2a=0.25$ mm; $T=9.7$ sec., $2a=0.042$ mm. The subsequent motion gradually diminished, the vibrations for the next 8^m being as follows:—$T=14.3$ sec., $2a=0.13$ mm; $T=10.4$ sec. The average period, deduced from 3 successive series, each of 30 vibrations, was as follows:—

$$\left.\begin{array}{l}16.1\text{ sec.}\\ 16.1\\ 17.9\end{array}\right\}\ \ldots\ \textit{mean},\ 16.7\text{ sec.}$$

30. ***Washington,*** D.C., U.S.A. ***NS Component.*** (See Pl. IX, the ***Publications***, No. 23.) U.S. Weather Bureau. (Professor C. F. Marvin.)

The record was furnished by the Weather Bureau (Omori type) Seismograph, whose instrumental constants were as follows:—

Multiplication = 10.
Oscillation period of pendulum = about 19 sec.

Time of commencement $=1^h\ 8^m\ 25^s$. Total Duration $=2^h\ 30^m$.

1st Preliminary Tremor. Duration $=15^m\ 2^s$. During the first $6^m\ 24^s$, the motion was very small and doubtful. During the remaining $8^m\ 38^s$ the period was as follows:—$T=43$ sec. (?); $T=6.3$ sec.

2nd Preliminary Tremor began at $1^h\ 23^m\ 27^s$. Duration$=12^m\ 9^s$. The motion was small:—$T=21.4$ sec.; 28 sec.; 39.5 sec.

Principal Portion began at $1^h\ 35^m\ 36^s$. [*1st and 2nd phases.*] Duration$=15^m\ 41^s$. The movements during the successive epochs were as follows.

(i) $5^m\ 10^s$:—Motion small and irregular:—$T=44.3$ sec. (?)
(ii) $3^m\ 18^s$:—Motion well defined:—$T=49.5$ sec., $2a=0.05$ mm.
(iii) $7^m\ 13^s$:—$T=27.8$ sec., $2a=0.08$ mm.

[*3rd phase.*] Commencement$=1^h\ 51^m\ 17^s$. Duration$=22^m\ 50^s$. During the first $2^m\ 16^s$, the motion was regular:—$T=19.4$ sec. (pend. oscillations), the max. $2a=1.2$ mm occurring at $1^h\ 52^m\ 39^s$. During the next $20^m\ 34^s$, the motion was much smaller and quicker:—$T=15.1$ sec. The subsequent motion was small.

W_2 began to appear at $2^h\ 27^m\ 28^s$, when the motion became distinctly larger, for about 10^m:—$T=16.5$ sec. Thereafter the motion was small, till about $2^h\ 52^m\ 30^s$, when there appeared again distinct slow vibrations, for $5^m 50^s$:—$T=27$ sec. At $2^h\ 58^m\ 43^s$, the motion became more distinct:—$T=21.9$ sec.; 13.5 sec. These movements lasted till $3^h\ 12^m\ 0^s$, the subsequent motion gradually decreasing.

31. *Cheltenham,* Maryland, U.S.A.

Magnetic Observatory of the U.S. Coast and Geodetic Survey. (Superintendent, Dr. O. H. Tittman; Observer, J. E. Burbank.)

The motion was recorded by a pair of Omori Horizontal Pendulums, whose magnification was 10, the oscillation periods of the pendulums being as follows:—

EW Component..........21 sec.
NS „ ....19 „

Time of earthquake occurrence $=1^h\ 8^m\ 39^s$. Total duration $=3^h\ 45^m$.

(**I**) ***EW Component.*** (Pl. IX, the *Publications*, No. 23.)

1st Preliminary Tremor. Duration $=14^m\ 42^s$. For the first $6^m\ 18^s$, the motion was very small and doubtful. For the next 8^m 24, the motion became slightly but distinctly larger, vibrations being greater at the commencement :—$T=12.3$ sec., $2a=0.05$ mm ; $T=7.8$ sec.

2nd Preliminary Tremor commenced at $1^h\ 23^m\ 21^s$. Duration $=12^m\ 14^s$. For the first 2 min. there were 3 slow vibrations :—$T=41$ sec., $2a=0.1$ mm. The subsequent motion consisted essentially of small regular vibrations :—$T=14.4$ sec., $2a=0.05$ mm.

Principal Portion began at $1^h\ 35^m\ 35^s$. [*1st and 2nd phases.*] Duration $=13^m\ 47^s$. The movements during the succesive epochs were as follows :—

(i) $3^m\ 53^s$......The motion was made up of 4 very slow vibrations : –

(*a*) 1st $2^m\ 8^s$ ....Two vibrations, $T=64$ sec.
(*b*) next 1 48 .... „ , „ $=54$ „ , $2a=0.12$ mm.

There were also some very slight vibrations of $T=$about 15.7 sec.

(ii) $3^m\ 02^s$......Motion irregular, $2a$ being nearly the same as before : $T=45.5$ sec. ; 22.4 sec.

(iii) $6^m\ 42^s$......Motion smaller :—$T=30.0$ sec., $2a=0.08$ mm ; $T=14.7$ sec.

[*3rd phase.*] Commencement $=1^h\ 49^m\ 12^s$. Duration $=11^m\ 0^s$. During the first $1^m\ 56^s$ the motion was small. The two max. $2a$'s of 0.83 mm (absolute maximum) and 0.60 mm occurred respectively at $1^h\ 52^m\ 54^s$ and $1^h\ 58^m\ 38^s$:—$T=19.7$ sec.

The subsequent motion was as follows :—

(i) $23^m\ 25^s$......Motion nearly constant:—T=15.2 sec., $2a$=0.2 mm; T=19.9 sec., $2a$=0.36 mm.

(ii) $29^m\ 12^s$......Motion very regular:—T=16.0 sec., $2a$=0.21 mm.

The vibrations occurred in groups whose mean interval was 3.0 minutes.

(iii) $5^m\ 20^s$......Motion small:—T=19.4 sec.

(iv) $4^m\ 5^s$......Motion slightly larger, and nearly uniform:—T= 21.3 sec., $2a$=0.1 mm.

The subsequent motion belonged to W_2.

W_2. The motion in the successive epochs was as follows:—

(i) $4^m\ 36^s$......Motion regular, forming a conspicuous maximum group:—T=19.7 sec., $2a$=0.28 mm.

The maximum motion occurred at about $2^h\ 4^m\ 18^s$.

(ii) $2^m\ 5^s$......Motion small.

(iii) 4 20......There was a 2nd maximum group:—T=17.4 sec., $2a$=0.11 mm.

Thereafter the motion gradually diminished, with alternations of max. and min. groups.

The record, as described above, consists almost entirely of the pendulum oscillations, whose mean period comes out to be 20.4 sec.

(II). ***NS Component.*** (Pl. IX, the *Publications*, No. 23.)

1st Preliminary Tremor. Duration=$14^m\ 45^s$. the movements during the successive epochs were as follows:—

(i) $6^m\ 0^s$......Motion very small:—T=7.1 sec.

(ii) $3^m\ 32^s$...... T=30.3 sec. (?)

(iii) $2^m\ 2^s$......There were 3 vibrations:—T=40.7 sec., $2a$=0.15mm.

(iv) $3^m\ 11^s$......Motion small: T=12.6 sec.

2nd Preliminary Tremor began at $1^h\ 23^m\ 23^s$. The duration was $12^m 16^s$.

(i) $1^{m}\ 32^{s}$......3 slow vibrations :—T=30.7 sec., $2a$=0.09 mm ; T =8.4 sec., $2a$=small.

(ii) $3^{m}\ 41^{s}$......Motion small :—T=11.2 sec.

(iii) $3^{m}\ 4^{s}$......3 slow vibrations :—T=46.0 sec., $2a$=0.07 mm.

(iv) $3^{m}\ 58^{s}$......Motion small :—T=24.6 sec., $2a$=0.06 mm.

Principal Portion began at $1^{h}\ 35^{m}\ 39^{s}$. [*1st and 2nd phases.*] Duration=$15^{m}\ 31^{s}$. The motion during the successive epochs was as follows :—

(i) $6^{m}\ 25^{s}$......Motion consisted of small irregular vibrations :—T =62.3 sec., $2a$=0.14 mm ; T=25.8 sec.

(ii) $2^{m}\ 0^{s}$.... T=48.0 sec., $2a$=0.09 mm ; T=14.1 sec.

(iii) $7^{m}\ 6^{s}$.... T=29.8 sec., $2a$=0.24 mm.

[*3rd phase.*] Commencement=$1^{h}\ 51^{m}\ 10^{s}$: Duration=$11^{m}\ 52^{s}$. Successive movements were as follows :—

(i) $2^{m}\ 58^{s}$......Motion was most active :—T=18.6 sec., $2a$=2.12 mm.

The maximum vibration (pendulum oscillation) was the 4th one, and occurred at $1^{h}\ 52^{m}\ 15^{s}$.

(ii) $4^{m}\ 3^{s}$......Motion small :—T=21.2 sec.

(iii) $4^{m}\ 54^{s}$......Motion again larger, and uniform :—T=16.3 sec., $2a$=0.57 mm (pendulum oscillations.)

[*4th phase.*] commencement=$2^{h}\ 3^{m}\ 2^{s}$; duration=$11^{m}\ 20^{s}$. The motion consisted entirely of the pendulum oscillations :—T=16.4 sec., $2a$=0.21 mm.

[*5th phase and end portion.*] Commencement=$2^{h}\ 14^{m}\ 22^{s}$. Successive movements were as follows :—

(i) $5^{m}\ 19^{s}$......Motion small.

(ii) $14^{m}\ 2^{s}$......Motion again larger, and nearly uniform :—$2a$=0.12 mm (pendulum oscillations).

(iii) $17^{m}\ 51^{s}$......Motion small :—T=21.6 sec., $2a$=0.05 mm ; T=15.8 sec., $2a$=0,1 mm, The subsequent motion belongs to W_2.

W_2 appeared at $2^h\ 51^m\ 27^s$. Successive movements were as follows :—

(i) $5^m\ 19^s$......Motion consisted of small slow vibrations :—$T=29.0$ sec., $2a=0.06$ mm.
(ii) $1^m\ 46^s$......Motion small :—$T=23.6$ sec., $2a=0.06$ mm.
(iii) $4^m\ 46^s$......Motion larger and regular :—$T=22.0$ sec., $2a=0.19$ mm.
(iv) $10^m\ 10^s$......Motion smaller : –$T=18.5$ sec., $2a=0.06$ mm.

Thereafter the motion gradually diminished, with some alternations of max. and min. groups.

W_3 occurred at $5^h\ 22^m\ 4^s$.

The period of the free pendulum oscillation comes out, on the average, to be 18.2 sec.

32. ***Tacubaya,*** Mexico.

Observatorio Astronomico Nacional Mexicano. (Director, Ing. F. Valle.)

The registers were furnished by a pair of Omori Horizontal Pendulums, whose magnification was 10, the oscillation periods of the pendulums being as follows :—

EW Component	........17.3 sec.
NS „	........17.6 „ .

Time of commencement $=1^h\ 11^m\ 25^s$.

(i) ***EW Component.*** (Pl. X, the *Publications*, No. 23.)

Total duration $=2^h\ 40^m$.

1st Preliminary Tremor. Duration $=16^m\ 38^s$, the beginning being marked by small but distinct vibrations. Motion was nearly uniform :—$T=7.7$ sec. ; $T=14.2$, *2nd Preliminary Tremor* began at $1^h\ 28^m\ 3^s$. Duration $=15^m\ 42^s$. Successive movements were as follows :—

(i) $6^m\ 30^s$......Motion distinct :—$T=32.2$ sec., $2a=0.10$ mm.; the maximum motion occurring at the commencement and end of this epoch.

(ii) $9^m\ 12^s$......Motion much smaller :—$T=11.7$ sec.

Principal Portion began at $1^h\ 43^m\ 45^s$. [*1st and 2nd phases.*] Duration $=18^m\ 4^s$. This phase is characterized by the appearance of well defined slow vibrations, the motion in the successive epochs being as follows :—

(i) $6^m\ 42^s$......Motion regular :—$T=57.4$ sec., $2a=0.1$ mm.

(ii) $3^m\ 3^s$ .....Motion regular :—$T=45.8$ sec., $2a=0.1$ mm.

(iii) $5^m\ 0^s$......Motion larger and quicker :—$T=37.5$ sec., $2a=0.12$ mm.

(iv) $3^m\ 19^s$......Motion very small :—$T=24.8$ sec.

[*3rd phase.*] Commencement $=2^h\ 1^m\ 49^s$. Duration $=14^m\ 52^s$. Motion was well defined. For the first $10^m\ 30^s$:—$T=22.5$ sec., $2a=0.12$ mm. For the next $4^m\ 22^s$:—$T=18.1$ sec., $2a=0.15$ mm.

[*4th phase, etc.*] Commencement $=2^h\ 16^m\ 41^s$. During the first $27^m\ 5^s$, the motion very gradually diminished :—$T=15.9$ sec.; 17.8 sec.; 17.1 sec.; 18.0 sec.; 21.2 sec.

Then followed the W_2 motion.

W_2 began at $2^h\ 43^m\ 46^s$. For the first $20^m\ 35^s$, the motion was well defined :—$T=18.0$ sec., $2a=0.1$ mm. Thereafter the motion became gradually small. The period of the proper pendulum oscillations, given above, are included between 15.9 and 18.1 sec., giving the average value of 17.5 sec.

(ii) ***NS Component.*** (Pl. X, the *Publications*, No. 23.)

Total duration $=3$ hours.

The 1st and 2nd preliminary tremors, 1st and 2nd phases of the principal portion were not well defined.

In the 1st preliminary tremor :—$T=8.9$ sec.

At $42^m 45^s$ after the commencement of the earthquake, there appeared slow vibrations, the movements in the successive epochs being as follows :—

(i) $2^m 15^s$...... $T=45.0$ sec., $2a=0.1$mm.

(ii) 2 41 ...... „ $=40.3$ „ , „ $=0.1$ „ .

Then the motion became small :—

(iii) $10^m 15^s$...... $T=24.5$ sec.

(iv) 1 57 ......Motion larger :—$T=23.4$ sec., $2a=0.12$ mm.

(v) 6 51 ......Motion quicker and most active :—$T=15.8$ sec., $2a=0.30$ mm (pend. osc.); the vibrations being specially large and uniform during the last $2^m 16^s$.

Then the motion gradually diminished :—

(vi) $5^m 25^s$...... $T=16.3$ sec.

W_2 occurred $1^h 37^m$ after the commencement of the earthquake, or at $2^h 48^m 25^s$, and the motion was, for the first 5^m, remarkably large and regular :—$T=19.4$ sec., $2a=0.48$ mm (pendulum oscillations.); this being much greater than W_1 or the earthquake proper. For the next $15^m 30^s$, the motion was smaller, but still active :—$T=16.0$ sec., $2a=0.15$ mm (pendulum oscillations).

The successive max. groups occurred at an average interval of $3^m 30^s$.

33. ***Quarto Castello,*** Florence, Italy. (Pl. XI, the *Publications*, No. 23.) Osservatorio Geodinamico (R. Stiattesi).

The earthquake was recorded by the Grande Pendolo Orizzontale (Stiattesi) and the Grande Microsismografo "Vicentini" *a pantografo.* The constants of these instruments were as follows.

Grande Pend. Oriz. (Stiattesi) :—

EW Component	Weight of the bob	=500 kg.
	Magnification	=50
	Proper period	=17.4 sec.
NS Component	Weight of the bob	=500 kg.
	Magnification	=50
	Proper period	=21.4 sec.
" Vicentini " a pantografo..	Weight of the bob	=500 kg.
	Magnification	=80
	Proper period	=4.6 sec.

The duration of the 1st preliminary tremor was as follows :—

Pend. Oriz., EW	7^m	20^s	mean, 7^m 17^s.
„ NS	7	9	
Vicentini	7	22	

The commencement of motion was somewhat obscure. If we take the first well-defined vibration, the time interval between the latter and the end of the 1st preliminary tremor was as follows :—Pend. Oriz. EW, 7^m 0^s; Pend. Oriz. NS, 7^m 0^s; Vicentini, 7^m 18^s.

(i) Pendolo Orizzontale. ***EW Component.***

Time of commencement=0^h 58^m 49^s. Total duration=2^h 47^m.

1st Preliminary Tremor. Duration=7^m 20^s. During the first 20 sec., the motion was very small. This was followed by a vibration of $2a=0.056$ mm, $T=7.4$ sec, the motion remaining active for the next 69 sec. The subsequent vibrations were as follows :— $T=4.3$ sec., $2a=0.04$ mm; $T=9.1$ sec., $2a=0.07$. The motion during the last 2^m 21^s of this portion was very small.

2nd Preliminary Tremor; 1st and 2nd Phases of Principal Portion. Commencement=1^h 06^m 7^s. Duration=14^m 40^s. The successive movements were as follows.

(i) $4^m\ 28^s$......The motion was active: — $T=9.7$ sec., $2a=0.26$ mm
$T=3.1$ sec. (?).

(ii) $3^m\ 17^s$......Motion small:—$T=4.9$ sec., $2a=0.04$ mm;
$T=8.2$ sec., $2a=0.10$ mm.

(iii) $6^m\ 55^s$: — $T=9.2$ sec., $2a=0.12$ mm; $T=4.9$ sec.

3rd Phase of Principal Portion, etc. The successive movements were as follows:—

(i) $4^m\ 50^s$: — $T=11.5$ sec., $2a=0.22$ mm; $T=11.5$ sec., $2a=0.22$ mm; $T=14.7$ sec., $2a=0.44$ mm; $T=7.1$ sec., $2a=0.034$ mm.

(ii) $6^m\ 0^s$....The motion was most active, this part corresponding to the epoch in the NS component, in which the motion was small and which followed the largest pendulum oscillations:— $T=18.1$ sec., $2a=1.2$ mm. (pend. osc.); $T=10.2$ sec., $2a=0.44$ mm.

(iii) $6^m\ 32^s$....Motion smaller: —
$T=18.6$ sec., $2a=0.34$ mm (pend. osc.)
„ $=14.6$ „ , „ $=0.57$ „
„ $=10.3$ „ , „ $=0.38$ „
„ $=4.8$ „ , „ small.

(iv) $9^m\ 20^s$....Motion regular: — $T=14.1$ sec., $2a=0.14$ mm; $T=7.9$ sec.

(v) $12^m\ 2^s$ .. Motion very small:—$T=16.5$ sec., $2a=0.09$ mm (pend. osc.)

(vi) $11^m\ 15^s$....Motion very small.

(The further continuation is not given in the copy.)

(ii) Pendolo Orizzontale. ***NS Component.***

1st Preliminary Tremor. Duration$=7^m\ 9^s$. For the first 14 sec., the motion was small and partly obscure. Then there took place the following vibration:—$T=7.0$ sec., $2a=0.08$ mm. The subsequent motion was small and nearly constant:—$T=4.3$ sec.; $T=6.4$ sec.

2nd Preliminary Tremor ; 1st and 2nd Phases of the Principal Portion. Commencement$=1^h\ 05^m\ 56^s$. Duration$=15^m\ 09^s$. The first $7^m\ 22^s$ probably corresponds to the *2nd preliminary tremor*, the vibrations being as follows :—

$T=11.1$ sec., $2a=0.25$ mm. ;
„ $=4.7$ „ , „ $=0.02$ „ ;
„ $=8.2$ „ , „ $=0.14$ „ ;
„ $=54.5$ „ , „ $=0.51$ „ .

the maximum vibration of the last set occurring at the commencement of this phase.

The next $4^m\ 22^s$ probably corresponds to the *1st phase of principal portion.* The motion was small :—$T=9.6$ sec., $2a=0.058$ mm ; $T=50.0$ sec., $2a=0.22$.

The remaining $3^m 21^s$ corresponds to the *2nd phase of the principal portion*, the motion becoming more active :—$T=8.3$ sec., $2a=0.30$ mm ; $T=29.8$ sec., $2a=0.44$.

3rd Phase of Principal Portion began at $1^h\ 21^m\ 05^s$. Duration $=8^m\ 15^s$. The successive movements were as follows :—

(i) $0^m\ 53^s$....Motion small ;—$T=15.2$ sec., $2a=0.63$ mm ; the maximum vibration occurring at the beginning.

(ii) $2^m\ 51^s$....The motion consisted of 8 large pendulum oscillations : – $T=21.4$ sec., $2a=4.9$ mm.

(iii) $2^m\ 29^s$....The motion became abruptly small : – $T=26.6$ sec., $2a=0.72$ mm ; $T=9.5$ sec., $2a=0.16$ mm.

(iv) $1^m\ 58^s$....Motion again larger : – $T=20.7$ sec., $2a=2.06$ mm (pend. oscl.) ; $T=8.5$ sec., $2a=0.14$ mm.

The motion during the subsequent phases was as follows.

(i) $15^m 42^s$....The motion was on the whole constant :—

$T=12.2$ sec., $2a=0.46$ mm. ;
„ $=14.6$ „(?), „ $=0.20$ „ ;
„ $=18.8$ „ , „ $=0.48$ „ .

(ii) $15^m 23^s$....The motion much smaller:—

T=16.8 sec., $2a$=0.22 mm.;
„=11.9 „ , „ =0.15 „ ;
„= 4.9 „ , small.

Thereafter the motion became much smaller.

(iii) *Comparison of the EW and NS Components.* The following table gives a comparison of the periods and amplitudes occurring in the two horizontal components.

Quarto Castello. EW and NS components compared.

EW Component.	NS Component.	2 Components taken together.
1st Preliminary Tremor.		
Duration=$7^m 20^s$......	$7^m 9^s$.	
T=4.3 sec., $2a$=0.04 mm	T=4.3 sec., $2a$=0.02 mm	T=**4.3** sec., $2a$=0.01 mm
— —	6.4 0.02	6.4 0.02
9.1 0.07	— —	9.1 0.07
2nd Preliminary Tremor.		
Duration=$7^m 45^s$......	$7^m 22^s$.	
T=4.9 sec., $2a$=0.04 mm	T=4.7 sec., $2a$=0.02 mm	T=**4.8** sec., $2a$=0.01 mm
9.0 , 0.26	8.2 0.14	**8.6** 0.26
— —	11.1 0.25	11.1 0.25
— —	54.5 0.51	54.5 0.51
1st and 2nd Phases, Principal Portion.		
Duration=$6^m 55^s$......	$7^m 43^s$.	
T=4.9 sec., $2a$=small.	T=— $2a$=—	T=4.9 sec., $2a$=— mm
9.2 , 0.12 mm	9.0 sec., 0.30 mm	**9.1** 0.30
— —	29.8 0.44	29.8 0.44
— —	50.0 0.22	50.0 0.22

EW Component.	NS Component.	2 Components taken together.
3rd Phase, Principal Portion.		
Duration = 10^m 50^s......	8^m 15^s.	
T = 6.9 sec., $2a$ = 0.031 mm	T = — $2a$ = --	T = 6.9 sec. $2a$ = 0.031 mm
10.9 , 0.41	9.0 sec., 0.16 mm	**10.0** 0.44
14.7 , 0.44	15.2 , 0.63	**15.0** 0.63
18.1* , 1.18	21.1* , 4.9	— 4.9
— —	26 6 , 0.72	26.6 0.72
4th, etc. Phases, and End Portion.		
T = 4.8, sec., $2a$ = small.	T = 4.9 sec., $2a$ = small.	T = **4.9** sec. $2a$ = — mm
— —	— —	9.1 0.38
9.1 , 0.38	12.1 0.46 mm	12.1 0.46
14.4 , 0 57	14.6 0.20	**14.5** 0.57
16.5 , 0.09	16.8 0.22	**16.7** 0.22
18.6 ,* 0.31	18.8 0.48	**18.8** 0.48

* Pendulum moiton.

34. ***Querce,*** Florence, Italy.

Osservatorio Geodinamico del Collegio "alla Querce." (Director, Padre Camillo Melzi d'Eril.)

The following is an analysis made on a lithographic reproduction of the records from two Stiattesi Horizontal Pendulums, which registered in the directions NW-SE and NE-SW, and whose magnification was 25; the diagram consisting almost entirely of the pendulum oscillations.

NW-SE Component.	NE-SW Component.
1st Preliminary Tremor.	
Duration = 7^m 15^s	.... 7^m 16^s
T = 3.7 sec.	.... 3.6 sec.
,, = 8.7 ,, ...	.... 7.8 ,,
$2a$ = 0.08 mm	.... 0.072 mm
The motion became larger 3^m 26^s after the commencement,	

2nd Preliminary Tremor and Principal Portion.

Large pendulum oscillations appeared at

$13^m 45^s$	$12^m 10^s$

after the commencement of the 2nd preliminary tremor, the motion remaining specially large during the next

	$18^m 58^s$ ($2a=6.2$ mm)	$24^m 48^s$ ($2a=2.2$ mm)
Pendulum period = 17.6 sec.	....	..............15.5 sec.

The absolutely greatest group in the (NW—SE) component occurred between $1^h 7^m 55^s$ and $1^h 8^m 46^s$.

Then the motion became smaller, but the pendulum oscillations remained still active for the next

$22^m 0^s$ ($2a=2.2$ mm)	$13^m 18^s$($2a=1.3$ mm.)

About 3 hours after the commencement of the eqke :—

T (of pend. oscln.) = 17.6 sec.....	.............16.2 sec.
End of motion....$4^h 22^m 43^s$	.............$4^h 45^m$

W_2: *NW—SE Component.*

The W_2 motion began at $3^h 10^m 50^s$. The vibrations during the successive epochs being as follows.

(i) $5^m 24^s$......Motion active:—$T=15.1$ sec., $2a=0.12$ mm.
(ii) $3^m 46^s$......Motion small.
(iii) $8^m 12^s$......Motion a little larger.
(iv) $6^m 38^s$......Motion again active:—$T=18.1$ sec., $2a=0.12$ mm.
(v) $4^m 16^s$......Motion small.
(vi) $4^m 13^s$......Motion slightly larger.
(vii) $4^m 31^s$......Motion active:—$T=18.0$ sec., $2a=0.14$ mm.
(viii) $4^m 36^s$......Most active:—$T=18.0$ sec., $2a=0.27$ mm.
(ix) $4^m 48^s$......Small.
(x) $6^m 16^s$......Very small,

Then there followed a series of small max. groups at an average interval of $4^m\,18^s$.

W_2: *NE—SW Component.*

In this component, the W_2 vibration continued for about $15^m\,30^s$, the motion being not so marked as in the other:—$T=21.3$ sec., $2a=0.03$ mm.

Periods of vibration. The real earthquake T's are those indicated in the 1st preliminary tremor, whose mean values are: $T=3.7$ sec.; $T=8.3$ sec. ($2a=0.08$ mm, NW—SE component.) All the other periods given above are due to the proper pendulum oscillation, being as follows:—

NW—SE Component.	NE—SW Component.
17.6 sec.	15.5 sec.
17.6	16.2
15.1	
18.1	
18.0	
18.0	

The mean periods for the two component pendulums thus come out to be 17.4 and 15.9 sec., respectively.

The following tabular statement of the elements of motion is taken from the "Bollettino dell'Osservatorio Geodinamico del Collegio alla Querce a Frienze," No. 4, 1905.

NE-SW Component.			NW-SE Component.		
Times.	T	$2a$	Times.	T	$2a$
h m s	sec.	mm	h m s	sec.	mm
0 59 08	3.5	1.5	0 59 08	3.8	1.5
1 06 23	16.1	25.0	1 06 23	9.5	19.0
1 18 54	16.3	38.0	1 21 51	17.7	121.0

NE-SW Component			NW-SE Component.		
Times.	T	$2a$	Times.	T	$2a$
h m s	sec.	mm.	h m s	sec.	mm.
1 25 11	15.6	57.0	1 28 19	17.6	152.0
1 35 21	16.3	38.0	1 35 42	18.6	95.0
2 04 25	16.4	10.0	2 04 40	19.1	13.0
3 25 21	19.9	1.5	3 28 19	17.2	4.0
3 49 28	34.4	0.3	3 58 25	17.5	0.5
4 22 43.	..(End)		4 45 00..	..(End)	

35. ***Ximeniano,*** Florence, Italy. Osservatorio Geodinamico, (Padre G. Alfani.)

Commencement $=0^h\ 58^m\ 33^s$. Total duration $=4^h\ 12^m$.

The following is a note on a lithographic copy of the record from a Tromometrografo Omori, whose instrumental constants were as follows: weight of the bob$=150$ kg, period of the free oscillation$=20$ sec., velocity of the smoked paper$=100$ cm per hour.

1st Preliminary Tremor. The motion was small and uniform :— $T=3.9$ sec.; $T=9.6$ sec.

2nd Preliminary Tremor. $T=8.7$ sec.; $T=16.8$ sec.

In the principal portion, the record consisted almost entirely of the proper pendulum oscillations, whose T in the two horizontal components were 17.1 and 17.2 sec., respectively.

The following list of the times of occurrence of the different phases of motion, of the periods and amplitudes (*unreduced* ranges of actual tracing), is taken from the *Bolletino Sismologico del l'Osservatorio Ximeniano*, N. 4, 1905. Abbreviations :—

Microsismografo Vicentini : Pantografo = *mP*
„ : Vertical = *m V*
Pendolo Orizzontale Stiattesi : EW = EW
„ : NS = NS
Tromometrografo Omori : NW-SE = TN
„ : SW-NE = TS.

Instruments.	I (1st Prel. Trem.)	II (2nd Prel. Trem.)	III (Princ. Portion). 1st ph.	2nd ph.	3rd ph.	IV (Tail.)	End.
	h m s	h m s	h m s	h m s	h m s	h m s	h m s
mP	0.58.44	1.06.12	——	1.16.14	——	1.26.44	2 16.00
mV	0.58.54	1.12.07	——	1.22.00	——	— —	——
NS	0.58.32	1.05.42	1.19.42	1.21.00	——	——	——
EW	0.58.35	1.05.47	——	1.22.00	2.03.00	3.02.00	5.10.00
TN	0.58.32	1.05.07	——	1.19.17	1.33.22	2.00.00	4. ?
TS	0.58.32	1.06.32	——	1.19.32	1.33.37	1.44 17	?

Period, in sec. *Amplitude*, in mm

Instruments.	I (1st Prel. Trem.)	II (2ndPrel. Trem.)	III 1st ph.	III 2nd ph.	III 3rd ph.	IV (Tail.)	I (1st Prel. Trem.)	II (2ndPrel. Trem.	III 1st ph.	III 2nd ph.	III 3rd ph.	IV (Tail.)
mP	?	irreg.	—	7.7	—	18.0	6.0	4.0	—	1.5	—	2.5
mV	2.5	——	—	12.5	—	—	1.4	0.5	—	0.5	—	—
NS	5.0	21.3	35.0	—	—	—	0.5	18.0	25.5	—	—	—
EW	4.4 20.0	18.0	—	18.3	17.7	17.5	1.0	7.0	—	16.0	100.	24.10
TN	3.0 6.0	20.0	—	17.2	18.0	16.9	—	—	—	—	—	—
TS	3.0 6.0	10.5	—	19.0	20.0	17.0	—	—	—	—	—	—

From the first table we obtain the following mean values :—

Time of commencent of the earthquake = $0^h\ 58^m\ 33^s$
„ „ 2nd prel. tremor = $1^h\ 5^m\ 47^s$.

36. ***Ischia***, Italy. (Pl. XII, the *Publications*, No. 23.) R. Osservatorio Geodinamico. (G. Grablovitz).

Pl. XII, the *Publications*, No. 23, gives the records furnished by the Grablovitz Horizontal Pendulums and the " vasca sismica " at

Porto d'Ischia, and those furnished by similar instruments at Grande Sentinella, Casamicciola. The following is a description of the best among those records, namely, the NS and EW components registered by the horizontal pendulums at Porto d'Ischia.

Time of commencement$=0^h\ 58^m\ 56^s$.

NS Component. Pendulum period$=13$ sec. *1st Preliminary Tremor* lasted $7^m\ 18^s$, the motin being small.

2nd Preliminary Tremor began with active pendulum oscillations of $T=13.3$ sec., the max. (abs.) $2a$ of 1.8 mm occurring at the commencement. The motion was small between $1^h\ 11^m$ and $1^h\ 21^m$, indicating the predominance of some slow movements. It became moderately active between $1^h\ 25^m$ and $1^h\ 35^m$, ($2a=1.2$ mm, $T=12.8$ sec.), there being 5 max. groups at an average interval of 2.4 min. For the next 9^m, between $1^h\ 35^m$ and $1^h\ 44^m$, the motion was small. Then took place, for about 2.5 min., a max. group of $2a=1.3$ mm, $T=13.6$ sec.,

Thereafter the motion rapidly decreased.

EW Component. Pendulum period$=17$ sec.

1st Preliminary Tremor. Motion was small.

2nd Preliminary Tremor, etc. For the first 16 min., the motion was small. Then, at $1^h\ 22^m$, there took place the max. (abs.) group, $2a=2.8$ mm, $T=16.4$ sec.; the motion continuing active for 14.5 min., till $1^h\ 37^m$. Then it became abruptly small, till at $1^h\ 47^m$ there took place a max. group of $2a=1.3$ mm. After $1^h\ 49^m$, the motion was very small.

37. ***Laibach,*** Austria-Hungary.

Erdbebenwarte. (Professor Albin Belar.)

The following is a note on the two horizontal component records furnished by Grablowitz-Belar Horizontal Pendulum.

Time of commencement $=0^h58^m51^s$.

1st Preliminary Tremor. Duration $=7^m\,17^s$. Motion very small :—$T=9.3$ sec.

For the next $11^m\,45^s$, the motion was well defined at first, but again gradually decreased :—$T=9.2$ sec. Then took place the max. group, the motion being active for the next $21^m\,30^s$:—$T=9.2$ sec.; max. recorded motion. in each component $=16.4$ mm (unreduced). Thereafter the motion became much smaller.

Record from Vicentini Seismograph of magnification $=100$.

Time of commencement :—

(EW)......$1^h\,58^m\,48^s$
(NS)......1 58 44
Mean......$1^h\,58^m\,46^s$.

Duration of 1st preliminary tremor :—

(EW)........ $7^m\;3^s$
(NS)........ 7 9
Mean..........$7^m\,7^s$.

38. ***Pola,*** Austria-Hungary.

K. k. Hydrographisches Amt, Abtheilung Geophysik. (W. Kesslitz.)

The record was furnished by a Microsismografo "Vicentini" *a tre componenti*, of magnification $=91$.

The following description of the seismograph is taken from a note kindly communicated to me by the Geophysical Department of the I. R. Hydrographical Office.

Vertical component : No indication.

NS component :—

$0^h\,58^m\,43^s$. Commencement.

$1^h\;6^m\;0^s$ Commencement of regular oscillations, which lasted till $1^h10^m30^s$. At first, $T=10^s$.

$1^h\,20^m\,36^s$. Regular oscillations appeared again, in a series of short max. groups.

$1^h\,23^m\,6^s$ to $1^h\,32^m\,12^s$:—A continuous series of regular oscillations.

The max. $2a$ of 0.01 mm was observed at $1^h\,21^m\,0^s$, $1^h\,25^m\,36^s$, and $1^h\,29^m\,12^s$. The period during the principal part was 12—13 sec.

End of motion. $1^h 34^m 1^s$.

EW component:—

$0^h\,58^m\,44^s$. Commencement of irregular (pendulum) vibrations, which, with varying intensity, continued till $1^h\,1^m\,14^s$.

$1^h\;\;0^m\;\;8^s$. $2a = 0.012$ mm, the motion then decreasing.

$1^h\;\;5^m\,55^s$. Beginning of regular vibrations, with occasional breaks.

$1^h\,18^m\,58^s$. Commencement of a continuous series of vibrations, composed of two systems of wave motion: the $2a = 0.009$ mm of regular oscillations took place at $1^h\,27^m\,10^s$.

At first $T = 10$ sec., later on $T = 12$ sec. From $1^h\,32^m\,58^s$ to $1^h\,50^m$, there were only isolated wave groups.

From the above description, we see that the duration of the *1st preliminary tremor* was as follows:

$$\left.\begin{array}{l}(EW)\ldots\ldots 7^m\,11^s\\ (NS)\ldots\ldots 7\;\;\,18\end{array}\right\}\ \textit{Mean}\ldots\ldots 7^m 15^s.$$

39. ***Triest,*** Austria-Hungary.

I.R. Marine Observatory. (Professor E. Mazelle).

The earthquake was recorded by a Vicentini microseismograph and also by a Rebeur-Ehlert horizontal pendulum.

Vicentini Microseismograph. The following analysis is taken from an original note kindly communicated to me by Professor Mazelle.

Time and amplitude.	Vertical	NS Component.	EW Component.
Beginning of 1st phase	$0^{\mathrm{h}}\ 58^{\mathrm{m}}\ 55^{\mathrm{s}}.7$	$0^{\mathrm{h}}\ 58^{\mathrm{m}}\ 43^{\mathrm{s}}.1$	$0^{\mathrm{h}}\ 58^{\mathrm{m}}\ 44^{\mathrm{s}}.9$
Maximum	0 59 25.7	0 59 49.1	1 01 8.9
Amplitude*	0.6 mm	0.7 mm	0.8 mm
Beginning of long regular vibrations	$1^{\mathrm{h}}\ 6^{\mathrm{m}}\ 5^{\mathrm{s}}.3$	$1^{\mathrm{h}}\ 5^{\mathrm{m}}\ 43^{\mathrm{s}}.1$	obscure.
Max. amplitude.*	0.3 mm	1.0 mm	0.5 mm
End	$2^{\mathrm{h}}\,20^{\mathrm{m}}$	$2^{\mathrm{h}}\,31^{\mathrm{m}}$	$2^{\mathrm{h}}\,06^{\mathrm{m}}$

(* The amplitude is given in actual size of the record, not divided by the multiplication ratio.)

The duration of the 1st preliminary tremor was :—

Vertical......$7^{\mathrm{m}}\ 10^{\mathrm{s}}$; NS Comp.......$7^{\mathrm{m}}\ 0^{\mathrm{s}}$

Rebeur-Ehlert Horizontal Pendulum. The record was taken photographically, there being three horizontal components as follows :—

(*A*) In the direction EW; (*B*) W60°N; (*C*) W60°S.

Time of occurrence$=0^{\mathrm{h}}\ 58^{\mathrm{m}}\ 56^{\mathrm{s}}$. Total duration$=3\frac{3}{4}^{\mathrm{h}}$ (*Pendulum A*). The preliminary tremor was not clearly indicated. Its duration was about $6^{\mathrm{m}}\ 14^{\mathrm{s}}$ (*Pendulum A*). The first active group of motion lasted as follows :—(*A*) record too faint; (*B*) 61^{m} (in the last 29.2^{m}, motion smaller and uniform); (*C*) 59.2^{m} (especially large for the first 38^{m}).

Then the motion became much smaller, and nearly uniform :—(*A*) Record too faint; (*B*) for 24.3^{m}; (*C*) for 24.0^{m}. Then the motion became again smaller and nearly constant :—(*B*) for 21.8^{m}; (*C*) for 20.3^{m}. Thereafter the motion was very small.

What seems to correspond to the W_2 motion occurred in the (*A*) pendulum register at $3^{\mathrm{h}}\ 13^{\mathrm{m}}\ 56^{\mathrm{s}}$. Later on there appeared in the 3 components, especially in Pendulum (*A*) register, a small maximum at $3^{\mathrm{h}}\ 54^{\mathrm{m}}\ 26^{\mathrm{s}}$,

40. ***Manila***, Philippine Islands. (Pl. XIII, the ***Publications***, No. 23.) The Philippine Weather Bureau. (Director, P. I. Algué, S. J.; Assitant, M. Saderra Masó.)

The record was furnished by a Vicentini Microseismograph, of the following specifications :—

Length of the pendulum = 1.5 metres.
Weight of the bob = 100 kg.
Period of free oscillation = 2.4 sec.

Time of commencement = $0^h\ 58^m\ 25^s$. Total duration, more than 2 hours.

The two horizontal components were set up in the directions WSW-ENE and NWN-SES.

	WSW-ENE Component.	***NWN-SES Component.***

1st Preliminary Tremor.

Duration	$6^m\ 46^s$	$6^m\ 30^s$
Motion small for the first	17^s	9^s

For the next 4 min. the record consists entirely of pend. oscillations of $T = 2.55$ sec. :—

[*]Max. $2a$	19.5 mm.	18.0 mm.

During the last $2^m\ 27^s$ of this portion, the motion was small.

2nd Preliminary Tremor.

Duration	?	$5^m\ 10^s$

The pendulum oscillation was specially large during

	$2^m\ 22^s$:—	$3^m\ 1^s$:—
Max. $2a$	14.8 mm	31.0 mm
T		2.7 sec.

---

[*] These and subsequent values of max. $2a$ in the Manila diagram are the *actual readings*, or those not divided by the multiplication ratio.

1st and 2nd Phases, Principal Portion.

Duration.... —	$6^m 10^s$

In this portion, the pendulum oscillation greatly diminished :—

Max. $2a$.......2.9 mm	2.0 mm

Proper earthquake motion :—

T...........14.3 sec.	——
Max. $2a$ .... 4.0 mm	——
T....... 7.8 sec.	8.2 sec......., *mean*, 8.0 sec.
Max. $2a$ .... 2.0 mm	3.0 mm.

Thereafter the quick pend. oscillations completety disappeared.

3rd, etc. Phases, Principal Portion.

Motion active and nearly constant for the first

$18^m 35^s$:—	$19^m 32^s$:—
T........... 9.5 sec.	9.3 sec.......*mean*, 9.4 sec.
Max. $2a$ ....Small	Small
T...........12.7 sec.	12.8 sec.......*mean*, 12.8 sec.
Max. $2a$ .... 5.4 mm	5.0 mm

The max. motion occurred at about $1^h 20^m 45^s$.

During the next 13 m, the motion was much smaller, but nearly constant, as follows :—

Duration....$13^m 30^s$	....$12^m 46^s$
T...........11.8 sec.	10.7 sec.......*mean*, 11.3 sec.
Max. $2a$ .... 1.9 mm	1.8 mm

Thereafter the motion gradually diminished.

At about $2^h 20^m$, there were some very slight motion :—

T...........16.5 sec.	17.8 sec.......*mean*, 17.2 sec.

This may correspond to the W_2 motion.

At 3^h there was still some trace of vibrations.

41. ***Rocca di Papa,*** Italy. (Pl. XIII, the *Publications*, No. 23.)

R. Osservatorio Geodinamico. (Prof. Agamennone.)

The following analysis of the records obtained at Rocca di Papa from the Microsismometrografo and Pendolo Orizzontale has been made on a lithographic reproduction, published by Professor Agamennone.

(*i*) Microsismometrografo "Agamennonne" :—

Mass of the bob = 500 kg.
Period of pendulum oscillation = 4.2 sec.
Multiplication = 70.

The two horizontal components were set up in the directions of NW—SE and NE—SW.

Time of commencement $= 0^h\ 58^m\ 51^s$.
Total duration, more than $1\frac{1}{4}^h$.

The motion began with very small movements, becoming well defined after 35 sec. During the first $12^m\ 7^s$, the vibrations were due to the pendulum oscillation, of T = 4.2 sec. and 2a's = 0.09 and 0.16 mm respectively in NW and NE components; the motion being much greater in the latter than in the former direction. The first $7^m\ 18^s$ of this epoch may probably be taken as the 1st preliminary tremor, the remaining $4^m\ 49^s$ indicating a much greater motion.

For the next $6^m\ 53^s$, the motion became smaller, on account of the absence of large pendulum oscillations; the amplitude remaining on the whole constant :—

$$T = 6.6 \text{ sec.} \ldots \begin{cases} 2a = 0.024 \text{ mm (NE)} \\ \text{,,} \ = 0.017 \text{ ,, (NW)} \end{cases}$$

$$T' = 13.8 \text{ sec.} \ldots\ldots \begin{cases} 2a = 0.033 \text{ mm (NE)} \\ ,, = 0.021\ ,,\ \text{(NW)} \end{cases}$$

For the next $4^{m}\,50^{s}$, there appeared slow vibrations :—

$$T' = 28.0 \text{ sec.} \ldots\ldots \begin{cases} 2a = 0.017 \text{ mm (NE)} \\ ,, = 0.017\ ,,\ \text{(NW)} \end{cases}$$

These were mixed with small movements of T=8.6 sec. For the next $9^{m}\,58^{s}$, the motion was nearly uniform and active :—

$T = 19.0$ sec., $2a = 0.036$ mm, in each component.

,, = 9.2 sec., ,, small.

$$,, = 11.8 \text{ sec.} \ldots\ldots \begin{cases} 2a = 0.036 \text{ mm (NE)} \\ ,, = 0.03\ ,,\ \text{(NW)} \end{cases}$$

For the next $15^{m}\,55^{s}$, the motion was small but more or less distinct :—

$$T = 15.1 \text{ sec.} \ldots\ldots \begin{cases} 2a = 0.021 \text{ mm (NE)} \\ ,, = 0.014\ \ \text{(NW)} \end{cases}$$

,, = 10.7 sec., (small).

Towards the very end :—T = 13.4 sec. ; 22.1 sec.

(*ii*) Pendolo Orizzontale, NS component :—

Weight of the bob = 60 kg.
Period of pendulum oscillation = 27.2 sec.
Multiplication. Natural size.

The motion consisted simply of the pendulum oscillations throughout.

42. ***Colaba,*** Bombay, India. (Pl. XIV and Pl. XX, the ***Publications***, No. 23.)

The Government Observatory. (Director, N. A. F. Moos.)

The following very complete note on the seismic observations at Colaba has kindly been furnished by Mr. N. A. F. Moos.

Seismic Record.

Instrument.	P. T. commenced at	Larger waves commenced at	Maximum.
Milne Seismograph.	$5^{h}\ 44.1^{m}$ —	$5^{h}\ 47.5^{m}$	
Colaba Seismograph.	$5\ 44\ 24$	$5\ 48.1$	
		Commenced at	
Float Record.	—	$5^{h}\ 44.8^{m}$	$5^{h}\ 49.4^{m}$
Balance Record.	—	$5\ 44.8$	$5\ 49.4$

Barograph.

Commencement.	Maximum.	Change.
$5^{h}\ 48^{m}$	$5^{h}\ 49.4^{m}$	0.02^{inch}

The above tables give a summary of the times, etc., at which the various instruments were affected by the disturbance. The time given is B. M. T., to convert which into G. M. T. deduct $4^{h}\ 51^{m}\ 15.7^{s}$.

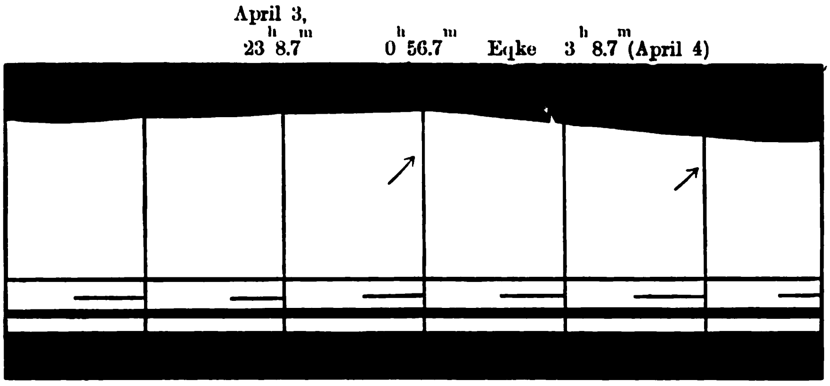

Fig. 6. Barograph, showing the Eq. effect. Colaba, Bombay. (The times are in G. M. T.)

" The preliminary tremors of the great seismic disturbance which occurred on the 4th April last, were picked up by the Milne's Seismograph at about $5^h\,44.1^m$ (Bombay time) and by the Colaba Seismograph (N—S) at $5^h\,44^m\,24^s$. There was a short temporary lull after the arrival of the preliminary waves—more clearly indicated by the open diagram of the Colaba Seismograph —and the larger waves followed $3.^m4$ later as registered by the Milne's and about $3^m\,37^s$ later as recorded by the Colaba Seismograph.

" Colaba Seismogralip No. 1 (E—W) was unfortunately writing very faintly and was displaced by the first shock of the larger movements and the record is incomplete.

" It is somewhat difficult to fix the exact time of occurrence of the maximum movement accurately as all the traces marking this phase are more or less blurred on account of the violence of the movement, except in one of the records of the Vertical movement Seismograph. In Milne's Seismograph the traces overlap.

" Both the seismographs for recording vertical movement have given fairly good records. The ' float ' record indicates the commencement of the movement at $5^h\,44.^m8$ and the maximum phase as can be approximately ascertained (the trace is blurred on account of the violence of the movement) at $5^h\,49.4^m$. This phase as also the commencement, both of which are clearly shown by the ' Balance ' Seismograph, are recorded exactly at the same time as the former. In the latter record, however, five distinct disturbances with intervals of lull are recorded, the time of the fourth —the largest movement corresponding with that of the maximum phase as indicated by the 'float' record. The larger movements of the disturbance continued to affect the Vertical motion Seismographs for about 30 minutes. The trace then runs normally smooth till $6^h\,31.3^m$ when the 'float' record again shows another disturbance but of much smaller magnitude, which attained its maximum at $6^h\,32.8^m$ and ended at $6^h\,37.9^m$. Yet a third disturbance of still smaller amplitude commenced at $6^h\,45.5^m$ and ended at $6^h\,47.1^m$.

"The disturbance as picked up by the Barograph shows the commencement at $5^h\,48^m$, the maximum effect having been registered in this instrument at $5^h\,49.4^m$. The change due to the oscillation in the column of mercury corresponds to a fall of .02 inch.

"The pulsation and after tremors of the convulsion as noted by the seismographs continued for about four hours, the last smallest being noted at about 10 hours."

43. ***Potsdam,*** Germany.

Royal Geodetic Institute, (Director, Prof. Dr. R. Helmert; Observer, Prof. Dr. O. Hecker.)

Photographic records from a pair of horizontal pendulums of Rebeur type, constructed by P. Stückrath, the magnification being 36. The apparatus was furnished with air damping, whose coefficient was 2.5.

Time of commencement $=0^h\,58^m\,46^s$. Total duration $=5$ hours.

(*i*) ***EW Component.*** Pendulum Period $=16.2$ sec.

1st Preliminary Tremor. Duration $=7^m\,16^s$. The record consists of the pendulum oscillations mixed with the following vibrations :—$T=5.4$ sec., $2a=0.12$ mm.

2nd Preliminary Tremor, Principal Portion, and End Portion. For the first $4^m\,42^s$, the motion which was greater at the commencement, consisted of the following two sets of vibrations :—$T=26.9$ sec., $2a=0.34$ mm ; $T=4.7$ sec., $2a=0.18$ mm. For the next $3^m\,40^s$, the motion was regular, the greatest movement occurring near the commencement :—$T=21.3$ sec., $2a=0.37$ mm ; $T=4.4$ sec., $2a=0.24$ mm. This epoch probably corresponds to the 1st phase of the principal portion. The vibrations in the next 3^m 11^s, which may correspond to the 2nd phase, was as follows :—

(i) $2^m 10^s$......3 vibrations, of $T=43.3$ sec., $2a=0.47$ mm.
(ii) 1 1......2 „ , „ „$=30.5$ „ , „ $=0.33$ mm.

These are mixed with the following two sets of motion :— $T=7.7$ sec., $2a=0.33$ mm ; $T=4.0$ sec. Then, at $1^h 17^m 29^s$, the motion became much larger, the vibrations in the successive epochs being as follows.

(i) $5^m 10^s$......Motion comparatively small :—
  (a) $1^m 58^s$...... $T=29.5$ sec., $2a=1.28$ mm.
  (b) 3 12...... „$=19.2$ „ , „ $=0.96$ „ .
(ii) $3^m 17^s$......Motion largest :—$T=16.4$ sec., $2a=2.5$ mm. This was due evidently to the pendulum oscillation.
(iii) $11^m 25^s$......Motion on the whole constant : - $T=14.4$ sec., $2a=1.18$ mm ; $T=20.0$ sec., $2a=1.0$ mm.
(iv) $17^m 40^s$......Motion small and nearly constant :—$T=15.8$ sec., $2a=0.57$ mm.
(v) $15^m 20^s$:—$T=15.1$ sec., $2a=0.35$ mm ; $T=24.1$ sec.
(vi) $13^m 35^s$:—$T=18.5$ sec., $2a=0.24$ mm.
(vii) $16^m 24^s$:—$T=17.3$ sec., $2a=0.14$ mm.

Thence the motion gradually decreased.

Those periods given above, which varies between 14.4 and 18.5 sec., are that of the pendulum oscillation. They give the mean value of 16.2 sec., as follows :—

$T=16.4$ sec.
14.4
16.2
15,3

15.1
18.5
17.3

W_2 The W_2 motion began to appear at $3^h 20^m 31^s$:—$T=20.0$ sec., max $2a=0.13$ mm. At $3^h 25^m 31^s$, the motion became distinctly larger, there being, for the next $4^m 4^s$, the second greatest (absolute) maximum :—$T=24.4$ sec., max. $2a=0.18$ mm. For the next $34^m 20^s$, the motion indicated on the whole very slight variation. Thereafter the vibrations became abruptly small : max. $2a=0.05$ mm.

(*ii*) ***NS Component.*** Pendulum period$=14.1$ sec.

1st Preliminary Tremor. Duration$=6^m 53^s$. The record is very obscure.

2nd Preliminary Tremor, and subsequent phases. The following well defined vibration occurred near the commencement :—$T=13.8$ sec., $2a=0.67$ mm ; the motion thence decreasing almost to zero at $1^h 08^m 29^s$ For the next $8^m 50^s$:—$T=11.0$ sec., $2a=0.55$ mm. Then, at $1^h 17^m 39^s$, began large vibrations. For the next $18^m 55^s$:—$T=55.2$ sec,, $2a=1.55$ mm. Thereafter the diagram consists entirely of the pendulum oscillations :—

Average period (deduced from 100 vib.)$=14.1$ sec.

W_2 appeared distinctly first at $3^h 40^m 16^s$; and consisted of the vibrations as follows :—$T=17.8$ sec., $2a=0.08$ mm. The motion continued altogether for an interval of $20^m 20^s$. Towards the very end :—$T=16.6$ sec.

44. ***Göttingen,*** Germany. (Pls. XV A and XV B, the *Publications*, No. 23.) R. Geophysical Institute. (Prof. Dr. E. Wiechert.)

The record was furnished by Prof. Wiechert's Astatic Pendulum, with damping arrangement, the mass being 1200 kg. The indicator-magnification was 160, the proper pendulum periods in the EW and NS components being 15.3 and 15.7 sec. respectively.

Time of Commencement$=0^{h}\ 58^{m}\ 55^{s}$. Total Duration$=4^{h}\ 40^{m}$.*

(*i*) ***EW Component.*** Pendulum period$=15.3$ sec.

The motion indicated in the diagram was very large and caused some confusion of the record from the superposition of successive lines, such that it was impossible to find out the parts corresponding to the 2nd preliminary tremor and the 1st and 2nd phases of the principal portion.

1st Preliminary Tremor. Duration$=7^{m}\ 25^{s}$. The movements in the successive epochs of this portion were as follows.

$$(\mathrm{i})\quad 2^{m}\ 0^{s}\ldots\left\{\begin{array}{l} T=\ 4.3\text{ sec.};\ 2a=3.4\text{ mm.}\\ ,,=\ 9.0\ ,,\ ;\ ,,\ =8.8\ ,,\ .\\ ,,=18.0\ ,,\ ;\ ,,\ =\ —\ ,,\ .\end{array}\right.$$

The vibrations of the last sort were those due to the pendulum oscillations.

$$(\mathrm{ii})\quad 3^{m}\ 50^{s}\ldots\left\{\begin{array}{l} T=\ 4.4\text{ sec.};\ 2a=5.8\text{ mm.}\\ ,,=11.7\ ,,\ ;\ ,,\ =7.0\ ,,\ .\end{array}\right.$$

(iii) $1^{m}\ 35^{s}$ ....The motion consisted of pendulum oscillations:—
$T=17.3$ sec.; $2a=14.0$ mm.

Principal Portion. During the first 7½ min., when the motion was greatest, the vibrations were as follows:—

$T=9.3$ sec.; $2a=113.0$ mm.

For the next 15 min., especially during the first 2½ min, the motion remained active consisting of large pendulum oscillations, as follows:—$T=16.4$ sec., $2a=102.5$ mm.

End Portion. Towards the very end of the earthquake motion the period, each deduced from 40 vibrations, was as follows :—

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* The range of motion ($2a$) is given in actual size as traced on the diagrams, not divided by the multiplication ratio.

4 hours after the commencement of Eq.: $T=17.9$ sec.;
3 „ „ : „ $=17.0$ „

The average value of the proper oscillation of the pendulum in the EW direction comes out to be 17.3 sec.

(*ii*) ***NS Component.*** Pendulum period $=15.7$ sec. The NS component record is clear, and the different phases of motion can be identified.

1st Preliminary Tremor. Duration $=7^{m}\ 8^{s}$. The motion was nearly uniform and consisted of the following two sets of vibrations :—

$T=8.5$ sec., $2a=4.0$ mm ;
„ $=4.5$ „ , „ —
„ $=2.2$ „ , „ —

2nd Preliminary Tremor. Duration $=7^{m}\ 40^{s}$.

$T=13.4$ sec., $2a=34.0$ mm ;
„ $=10.2$ „ , „ $=25.0$ „

Principal Portion. [*1st and 2nd phases.*] Duration $=6^{m}\ 35^{s}$. During the first $4^{m}\ 50^{s}$, the motion consisted of the following two sets of slow vibrations, mixed with some pendulum movements :—

(i) For $2^{m}\ 25^{s}$: $T=48.3$ sec., $2a=47.0$ mm.
(ii) „ 2 24 : „ $=36.0$ „ , „ $=55.0$ „ .

During the remaining $1^{m}\ 47^{s}$, the motion became very large, the period again quickening slightly :—$T=30.6$ sec., $2a=109$ mm.

[*3rd phase.*] Duration $=5^{m}\ 55^{s}$. The motion became quicker and large :—

$T=11.0$ sec., $2a=110$ mm.
„ $=15.0$ „ , (pend. oscillation.)

For the next $5^{m}\ 35^{s}$, the motion was smaller, but still active :—

$T=\ 9.5$ sec., $2a=74.5$ mm.
„ $=14.5$ „ , „ $=112$ „ , (pend. oscillation.)

For the next $13^m\ 20^s$:—

$T=$ 9.5 sec., $2a=67$ mm.
„ $=14.1$ „ , „ $=69$ „ . (pend. oscillation.)

End Portion. The period towards the end of the earthquake was as follows :—

3 hours after the commencement of Eqke.,. . . . $T=17.8$ sec.
4 „ „ , „ $=17.5$ „

W_2. In the end portion of the W_1 motion, the mean period was 17 sec. At $3^h\ 20^m$ there began the W_2 motion consisting of slow vibrations of $T=25$ sec., the latter decreasing to 20 sec. at $3^h\ 32^m$. After a series of max. and min. groups, a large motion of $2a=0.07$ mm is reached in the EW component at $3^h\ 45^m$.*

The following tabular statements of the results of the observation is taken from Mr. G. Angenheister's paper : " Seismische Registrierungen in Göttingen im Jahre 1905,"†

Phase of motion.	Times.	T	$2a$		Acceleration (milligal)	
			EW.	NS.	EW	NS
Commencement.	$0^h\ 58^m\ 55^s$	1-4 sec.	50 μ	5 μ	—	—
		20-25	40	—	0.2	—
2nd Prel. Tremor.	1 06 08	15	—	200	—	2
		10	—	60	—	1
		15	140	—	1	—
Maximum (NS).	1 19 00	10	400	600	8	12
Maximum (EW).	1 22 00	10	700	700	14	14
Tail (End Portion).	—	17				
End.	5 40					

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* This remark on W_2 is based on a note given in Mr. G. Angenheister's " Seismische Registrierungen in Göttingen im Jahre 1905."

† Nachrichten der K. Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-physikalische Klasse, 1906.

45. ***Leipzig,*** Germany. Erdbebenstation. (Director, Prof. Dr. Credner; Observer, F. Etzold.) Wiechert's Astatic Pendulum Seismograph*:—

Pendulum weight = 1100 kg. Indicator-Multiplication = 250.
Pendulum period = 9.2 sec.

Time of Commencement = 0^h 58^m 44^s. Total Duration = 2^h $08.^m$

(*i*) ***EW Component.*** (Pl. XIV, the *Publications*, No. 23.)

1st Preliminary Tremor. Duration = 7^m 06^s. The motion, which is much more pronounced than in the NS component, began very gradually; the quick vibrations predominating during the first 4^m 25 sec. The period of slow movements was $T = 10.7$ sec. The end of this phase was not well marked.

2nd Preliminary Tremor. Duration = 7^m 48^s. For the first 3^m 06^s, the motion was almost similar to that in the latter part of the 1st preliminary tremor, consisting of small quick vibrations mixed with slow ones of $T = 10.0$ sec. Then there appeared some slow vibrations, mixed with others, as follows:—$T = 48.0$ sec., $2a = 3.0$ mm; $T = 9.4$ sec., $2a = 1.5$ mm; $T = 16.2$ sec., $2a = 2.8$ mm.

1st and 2nd Phases, Principal Portion. Duration = 8^m 07^s. The motion began with two slow vibrations:—$T = 49.2$ sec., $2a = 3.0$ mm. Then there followed 5 gradually increasing vibrations:—$T = 29.7$ sec., $2a = 11.6$ mm. The remainder of these phases consisted of 8 vibrations:—$T = 29.4$ sec., $2a = 10.0$ mm. The superposed vibrations were:—$T = 9.2$ sec., $2a = 28.0$ mm, this latter max. movement having occurred at 0^h 23^m. [*3rd phase.*] For the first 4^m 33^s, the motion was most active, the max. vibration having occurred at 1^h 23^m 06^s:—$T = 9.1$ sec., $2a = 88.0$ mm; $T = 29.1$ sec. (?).

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* In the following analysis of the seismograms, $2a$ is given in the natural size of the record, not divided by the multiplication ratio.

The subsequent motion was smaller:—$T=9.0$ sec.; 12.0 sec.; 21.5 sec.; 24.3 sec.

(*ii*) ***NS Component.*** (Pl. XIV, the *Publications*, No. 23.)

1st Preliminary Tremor. Quick vibrations were mixed with slow ones of periods $T=4.3$ sec., $T=7.9$ sec,

2nd Preliminary Tremor. Duration$=7^{m}\,25^{s}$. The commencement of this phase was clearly marked by the appearance of slow large vibrations, which were only slightly shown in the EW component. The first vibration was:—$T=38.0$ sec., $2a=8.5$ mm; mixed with smaller ones of $T=9.5$ sec., $2a=10.5$ mm. For the next $1^{m}\,56^{s}$, the motion was small:—$T=14.0$ sec., $2a=1.4$ mm. Then at $1^{h}\,08^{m}\,48^{s}$, there began again slow vibrations, the first two of which were well defined:—$T=46.9$ sec., $2a=7.0$ mm. Towards the end of this phase:—$T=4.5$ sec.; $T=13.1$ sec., $2a=4.0$ mm.

Principal Portion. This phase began at $1^{h}\,13^{m}\,31^{s}$. For the first $3^{m}\,26^{s}$, the motion was small:—$T=9.7$ sec., $2a=11.0$ mm; $T=36.6$ sec. For the next $1^{m}\,23^{s}$, the motion was larger:—$T=8.8$ sec., $2a=37.0$ mm; $T=37.0$ sec. For the next $7^{m}\,45^{s}$, the motion was most active, commencing at $1^{h}\,18^{m}\,25^{s}$ with 2 large vibrations:—$T=8.9$ sec., $2a=67.0$ mm; mixed with slow one of $T=20.3$ sec. The 2nd max. $2a$ of 59.5 mm occurred at $1^{h}\,25^{m}\,04^{s}$, and during the interval between these two epochs, there were 7 sub-maxima, the first 6 of which occurred at nearly regular intervals of $1^{m}\,18^{s}$ (average).

For the next $5^{m}\,23^{s}$, the motion was smaller:—$T=11.0$ sec., $2a=27.5$ mm; $T=22.7$ sec. For the next $4^{m}\,45^{s}$, the motion became again smaller:—$T=21.6$ sec., $2a=14.0$ mm. The subsequent motion was still smaller:—$T=22{,}8$ sec,, $2a=8{,}0$ mm; $T=9{,}3$ sec, The following tabular statement of the elements of motion is taken from Mr. F. Etzold's 6th Report on the Leipsic Seismic Observation.[*]

Phase of motion	Times.	$T.$	$2a$ (NS)	$2a$ (EW).
Commencement.	$0^h\ 58^m\ 44^s$	1 sec. 4	4-8 μ 7	4-10 μ 11
2nd Prel. Tremor.	1 05 53	12	60	
„ (NS).	1 08 48	ca. 55	930	
Long Waves.	1 13 30			
Prominent Vibration (EW).	1 23 05	13		600
„ „ (NS).	1 18 27	9	211	
„ „ (EW).	1 26 55	12		213
„ „ (NS).	1 23 14	12	322	
„ „ (NS).	1 25 58	10	256	
Tail, or End Portion.		24-8		
End.	3 06 15			

46. ***Upsala,*** Sweden, (Pl. XVI, the *Publications*, No. 23).

Meteorological Observatory. (Director, Prof. Hildebrandsson. Observer, Filip Akerblom).

Wiechert's Astatic Pendulum Seismograph[*]:—

Weight of the heavy mass = 1000 kg.
Indicator-Multiplication = 235.
Pendulum period = about 9 sec.
Relaxation time = about 5 sec.

Commencement = $0^h\ 58^m\ 22^s$. Total Duration = $3^h\ 7^m$.

(i) NS Component.

1st Preliminary Tremor. Duration = $6^m\ 51^s$. The motion began with very small but distinct vibrations of $T=5.2$ sec., which in 35 sec. gradually reached a max. $2a$ of 8.6 mm. At first there were also some small quick movements.

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[*] Berichte der Mathematisch-physikalischen Klasse der königlich sächsischen Gesellschaft der Wissenschaften zu Leipzig. LVIII. Band.

[*] $2a$ is given in the natural reading, not divided by the multiplication ratio.

For the next $1^m\,34^s$, the motion was small:—$T=6.5$ sec.; $T=2.5$ sec. Then there took place the 2nd max. group, consisting of 2 conspicuous vibrations, as follows:—$T=5.0$ sec., $2a=19.0$ mm. During the whole remainder of this phase, the motion was nearly constant:—$T=4.5$ sec., $2a=8.0$ mm; $T=9.1$ sec.

2nd Preliminary Tremor, etc. The 2nd preliminary tremor began with a max. group, which lasted 44 sec.:—$T=8.9$ sec., $2a=24.0$ mm. The movements during the successive epochs were as follows:—

(i) $2^m\,18^s$....Motion small:—

$T=8.7$ sec., $2a=8.0$ mm; $T=5.7$ sec., $2a=10.0$ mm

(ii) $3^m\,45^s$....Motion larger:—

$T=6.9$ sec., $2a=47.0$ mm; $T=13.2$ sec.

(iii) $4^m\,18^s$....Motion again larger:—

$T=8.4$ sec., $2a=66.0$ mm; $T=15.9$ sec.

Then the motion became very large, commencing with one of $T=13.4$ sec. The subsequent vibrations became quicker and gradually increased in amplitude:—$T=9.6$ sec., $2a=181.0$ mm (max. limit). The pointer then went off the smoked paper.

(*ii*) ***EW Component.***

1st and 2nd Preliminary Tremors. The motion began with small vibrations, which reached a maximum 17 sec. after the start, thence again decreasing:—

$T=7.3$ sec., $2a=10.5$ mm; $T=3.7$ sec., $2a=4.5$ mm; $T=2.5$ sec. (?)

The 2nd max. occurred $2^m\,9^s$ after the commencement:—$T=8.4$sec., $2a=28.0$ mm. The subsequent motion was small:—$T=3.8$ sec., $2a=12.0$ mm.

The 3rd max. occurred $6^m 50^s$ after the commencement and consisted of 4½ vibrations, lasting for 45 sec.;—$T=10.1$ sec., $2a=30.6$ mm.

The motion for the next successive epochs were as follows :—

(i) $3^m 06^s$....Motion small :—
$T=4.9$ sec., $2a=15.0$ mm ; $T=12.1$ sec.

(ii) $2^m 39^s$....Motion larger and slower :—
$T=14.5$ sec., $2a=33.0$ mm(?) ; $T=7.8$ sec., $2a=34$ mm.

(iii) $4^m 41^s$....Motion much greater :—
$T=7.3$ sec., $2a=50.0$ mm ; $T=5.5$ sec., $2a=30.0$ mm ;
$T=12.7$ sec., $2a=38.5$ mm.

3rd Phase, Principal Portion. For the first $3^m 58^s$, the motion was most active, comprising the following three max. groups :—

1st group....... $T=$ 9.1 sec., $2a=200$ mm.
2nd „ ...... $T=$ 8.7 „ , „
3rd „ ...... $T=13.4$ „ , $2a=205$ mm (max. limit.)

During the next $12^m 32^s$, the successive max. movements gradually diminished from 198.0 mm to 46.0 mm ; the first 5 max. vibrations were conspicuous and occurred at nearly regular intervals, as follows :—

Interval between 1st and 2nd max. $=1^m 39^s$.
„ 2nd „ 3rd „ $=1$ 52
„ 3rd „ 4th „ $=2$ 05
„ 4th „ 5th „ $=1$ 38

The period of the principal vibrations in the max. group was :—$T=9.7$ sec. But at min. places there were the following slow movements.:—$T=13.8$ sec.; $T=21.5$ sec.

For the next $10^m 10^s$, the motion was much smaller and nearly uniform, there being 7 maxima which occurred at nearly regular intervals of $1^m 41^s$ (average). These maxima ranged between 16.0 (1st max.) and 21.5 mm (5th max.), and the period was $T=$

12.2 sec. At min. epochs there were also some vibrations of $T=22.3$ sec.; $T=8.7$ sec.

Thereafter the motion was much smaller:—$T=11.2$ sec., $T=26.6$ sec. Towards the end of the earthquake:—$T=14.8$ sec.

The following tabular statement of the elements of motion is taken from Mr. F. Akerblom's Report on the seismic observations at Upsala, Oct. 1904 to May 1905.*

Phase of motion.	Times.	T	$2a$(EW)	$2a$(NS)
Commencement.	h m s 0 58 22	sec. 1.5	μ 5	μ 1
		5	35	30
Increase of motion.	1 00 31	5	90	60
2nd Preliminary Tremor.	1 05 19			
		7	80	60
		15		
Long Waves.	1 12.6			
Prominent Vibration.	1 17.4	9	600	540
"	1 20.2	9	620	
Tail (End Portion).		16		
End.	4 05			

47. ***Batavia,*** Java.

The Royal Magnetic and Meteorological Observatory. (Director, Dr. S. Figee. Vice Director, Dr. W. van Bemmelen.)

EW Component motion photographically registered by a Rebeur-Ehlert Horizontal Pendulum, whose oscillation period was 9.8 sec., and whose period, when suspended vertically, was 1.32

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* Nachrichten der. K. Gesellschaft der Wissenschaften zu Goettingen. Math.-physik. Klasse. 1906.

seconds, so that 1 mm displacement on the photogram would correspond to a tilt of 0,″159.

Time of commencement$=0^h\ 58^m\ 33^s$. Total duration$=3^h 50^m$.

1st Preliminary Tremor. Duration$=7^m\ 0^s$. The motion consisted chiefly of the following 3 sets of vibrations :—$T=5.9$ sec.; $T=9.8$ sec.; $T=1.4$ sec. The last period characterizes movements of a macroseismic nature. Then set in large pendulum oscillations, which remained active till about $1^h\ 48^m$, the motion thence gradually diminishing,

In the epoch, which may correspond to the 1st and 2nd phases of the principal portion, there were some large slow vibrations of $T=18.8$ sec., mixed with pendulum oscillations. For the next $19^m\ 3^s$, the motion was large, as follows :—$T=11.4$ sec., max. $2a$ (actual record)$=57$ mm.

For the next 10 m., the motion, which was smaller, was as follows :—$T=10.0$ sec., max. $2a$ (actual record) $=18.5$ mm. Towards the very end, $T=9.4$ sec.

The different values of the period above given, nearly equal to 10 sec., are due to the pendulum oscillation ; these are

$$\left.\begin{array}{r}9.8 \text{ sec.}\\ 11.4\\ 10.0\\ 9.4\end{array}\right\}\ \textit{mean},\ 10.2 \text{ sec.}$$

The trace of the W_2 motion was not indicated, probably on account of the shortness of the free oscillation of the pendulum.

Pulsatory Oscillations.

The diagram indicated small pulsatory oscillations, both before and after the earthquake. Their periods, deduced from 5 series, each of 80 vibrations, were as follows :—

Before the earthquake....	7.4 sec. 7.5 8.0 7.3
After the earthquake	7.6
Mean	7.6 sec.

This corresponds to what I have denoted by Q_2. (See § 8).

48. ***Zikawei,*** (Shanghai), China: Observatory (Director, L. Froc). ***Rio de Janeiro,*** Brazil: Observatorio do Rio de Janeiro (Director, H. Morize). The seismic records at these two places, furnished by the Omori horizontal pendulums, were not satisfactory.

Strassburg, Germany: Kaiserliche Hauptstation für Erdbebenforschung (Director, Prof. Dr. G. Gerland). The copies of the diagrams furnished by Rebeur-Ehlert horizontal pendulum and the Vicentini microsismografo were not clear enough to allow us to study them in detail.

The times of the earthquake occurrence at the above mentioned 3 places have been given in Table I.

49. *Earthquake Observations at Taschkent, Irkutsk, Tiflis, Achalkalaki, Batum, Borshom, Derbent, Schemacha, Jurjew (Dorpat), Nikolajew, Belgrade, Krakau, Jena, Hamburg, Padova, Messina, Apia, Vieques.* The results of the earthquake observations at these 18 stations, given in tabular form in §§ 37–53, are taken from the different seismological periodical reports.

50. ***Taschkent,*** Russian Turkestan.

Astronomical and Physical Observatory. (Observer, J. Goultiaeff.)

The times of the different parts of the earthquake motion recorded by Omori seismographs and a Rebeur-Ehlert pendulum were as follows.[*]

(In Taschkent Time)	Omori	Rebeur-Ehlert	Mean (G. M. T.)
	h m s	h m	h m s
Commencement of Eq.	5 29 35	5 29.6	0 52 24
,, of 2nd prel. tremor	5 31 37	5 31.7	0 54 29
Maximum motion	5 34 33		0 57 22
End	——	10 4.2	5 27 00

Thus the duration of the preliminary tremor was $2^m\ 5^s$.

After-shocks. The arcual distance between the earthquake origin and Taschkent was only 1260 km and it is possible that the shaking was actually felt at the latter place. In the course of the succeeding two days, the seismographs there recorded 11 small seismic disturbances, as shown in the following list.

Date.	Time of Commencement.[†]	Time of Maximum.[†]	Time of Commencement (G. M. T.)	Max. 2a
	h m	h m	h m s	mm
April 4th.	12 31.6	12 31.6 (NS)	7 54 25	2.0
	13 4.0	13 4.0 (EW)	8 26 49	2.8
	13 19.6	13 19.6 (EW)	8 42 25	2.5
	14 12.7	14 12.7 (EW)	9 35 31	2.0
	15 10.0	15 10.0 (EW)	10 32 49	2.4
	15 24.9	15 27.9 (EW)	10 47 43	4.0

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[*] Taken from Monatsberichte der Horizontalpendel-Station am Astronomischen und Physikalischen Observatorium zu Taschkent. No. 4, 1905.

[†] Taschkent Time.

Date.	Time of Commencement.	Time of Maximum.	Time of Commencement (G. M. T.)	Max. 2a
	h m	h m	h m s	mm
April 4th.	15 51.9	15 51.9 (EW)	11 14 43	3.3
	17 14.9	17 14.9 (NS)	12 37 43	10.2
	22 9.3	22 9.3 (NS)	17 32 07	2.0
	23 16.1	23 19.7 (NS)	18 38 55	3.5
April 5th.	3 44.6	3 47.0 (EW)	(April 4th) 23 07 25	5.8

51. ***Irkoutsk,*** Siberia.*

L'Observatoire Magnétique et Météorologique. (Directeur, A. Voznessensky).

Instrument.	Commencement.	Increase of motion (or minimum).	Maximum.	End (or weakening)	2a
	h m	h m	h m	h m	mm
Zöllner-Repsold Pendulum. NS.	0 55.7	—	0 57.3	—	42.0
	—	—	0 58.3	—	75.0
	—	1 1.1	1 02.9	—	176.4
	—	—	1 07.0	—	202.0
	—	3 20.6	3 28.6	—	22.8
	—	—	3 43.6	—	22.8
	—	—	4 11.9	8 16	20.0
Zöllner-Repsold Pendulum. EW.	0 55.7	—	0 56.9	—	31.6
	—	1 00.8	1 01.0	—	78.0
	—	—	1 01.6	—	227.2
	—	—	1 05.7	—	226.0
	—	3 09.8	3 17.2	—	20.0
	—	—	3 44.6	8 09	28.8

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* See Bulletin de la Commission Centrale Sismique Permanente. Année 1905, Avril-juin. St.-Pétersbourg.

Instrument.	Commencement.	Increase of motion (or minimum).	Maximum.	End (or weakening)	$2a$
	h m	h m	h m	h m	mm
Milne Hor. Pendulum. NS.		0 55.7	—	—	4.0
		—	0 56.7	—	4.6
		—	1 00.7	—	26.0
		—	1 05.7	—	40.0
		—	—	—	>40.0
		—	—	—	15.6
		—	1 25.3	—	22.4
		—	—	—	10.0
		—	—	1 48	8.8
		—	—	2 27	—
		—	—	>2 36	—
Omori Horizontal Pendulum. NS.	0 55.8	0 56.1	—	—	—
	—	1 00.8	1 01.0	—	12.0
	—	—	1 01.2	—	25.0
	—	—	1 01.6	—	54.8
	—	1 05.0	1 07.2	—	60.0
	—	—	1 08.3	—	104.0
Omori Horizontal Pendulum. EW.	0 55.8	1 00.9	1 01.5	—	28.0
	—	1 05.3	1 06.1	—	36.0
	—	—	1 06.8	—	66.0
	—	—	1 07.2	1 08	88.0
	—	1 21.1	—	2 17	—

The mean time moments of the different phases and the duration of the 1st preliminary tremor are as follows :—

Time of Eq. Commencement, t_1, $=0^h\ 55^m\ 46^s$
Commencement of 2nd Prel. Tremor, t_2, $=1\ 00\ 52$
Duration of the 1st Prel. Tremor, y_1, $=\ 5^m\ 06^s$

52. ***Tiflis, Achalkalaki, Batum, Borshom, Derbent, Schemacha,*** Caucasus, Russia. Tiflis : Physical Observatory, (Director, S. v. Hlasek ; Assistant, P. E. Stelling).

The positions and the results of the observations at Tiflis and the above named 5 adjacent stations are given in the following tables*

Place.	φ	λ
Tiflis	41° 43′ 8″ N	44° 47′ 51″ E
Achalkalaki	41 25	43 29 09
Batum	41 40	41 38 35
Borshom	41 51	43 23 08
Derbent	42 04	48 18
Schemacha	40 38	48 38

Observations at Tiflis. (Tiflis time.)

Instrument.			1st Preliminary Tremor.	2nd Prel. Tremor.	End.	Max. Motion.	
			h m s	3^h59^m+	h m	4^h+	
R.E.	facing	W 30° S	3 54 57	—	—	—	—
	,,	N	3 55 03	—	—	—	—
	,,	E 30°s	3 55 00	—	—	—	—
Milne,	,,	S	3 55 00	42^s	9 —	13^m00^s	31.6^{mm}
Omori	,,	N	3 54 54	46	6 30	8 26	11.7
	,,	E	3 55 10	32	8 —	?	>48.
Zoellner	,,	N	3 54 54	50	6 30	13 18	6.5
	,,	E	3 55 06	34	8 —	9 50	30.6
Omori	,,	N	3 54 52	52	7 30	13 34	22.7
	,,	E	3 54 48	28	——	9 42	35.2
Cancani	in meridian.		3 55 00	57	5 —	5 06	9.4
	in prime vertical		3 55 00	38	——	0 49	26.8

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* Taken from *Seismische Monatsberichte des Physikalischen Observatoriums zu Tiflis.* No. 4, 1905.

The reduction to the G. M. T. is $-2^h\ 59^m\ 11^s$, and we obtain from the above table the following mean values for the times of commencement of the 1st and 2nd preliminary tremors:

1st prel. tremor......$0^h\ 55^m\ 48^s$ (G. M. T.)
2nd „ „ ......1 00 31 („)

The duration of the 1st preliminary tremor was thus $4^m\ 43^s$. With regard to the times of occurrence of the maximum vibration, the majority of these may be divided into the following two groups:—

(*A*) $4^h\ 13^m\ 00^s$ (*B*) $4^h\ 8^m\ 26^s$
13 18 9 50
13 34 9 42

Mean ..$4^h\ 13^m\ 17^s$ ....$4^h\ 9^m\ 19^s$ (in Tiflis Time)
=1 14 6 ....1 10 8 (in G. M. T.)

(*B*) may probably be taken as corresponding to the commencement of the 3rd phase of the principal portion.

Observations at Achalkalaki, etc. (Tiflis Time)

Station.	Instrument.*	1st Prel. Tremor.	2nd Prel. Tremor.	End.	Max. Motion.	
		3^h+ m s	h m s	h m	h m s	mm
Achalkalaki.	Omori H.P. (N)	55. 7	4.00.05	6.20	4.07.45	20.7
	„ (E)	55.12	3.59.45	?	4.08.29	31.7
Batum.	„ (N)	55.39	4.00.31	5.30	4.11.31	27.4
	„ (E)	55.20	4.00.13	?	4.06.52	58.3
Borshom.	„ (N)	55.02	4.00.04	?	4.09.20	17.0
	„ (E)	55.04	3.59.46	5.30	4.09.51	31.3
Derbent.	?	54.12	3.58.40	8.—	—	>61.4
	?	54.16	3.58.32	—	—	>111.0
Schemacha.	Omori H.P. (N)	54.20	3.58.55	?	—	>127.0
	„ „ (E)	—	—		—	—

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* (N) and (E) mean respectively the pendulum facing N and the pendulum facing E.

From the above table we obtain, by taking the mean from the two components at each station, the times of commencement of the 1st and 2nd preliminary tremors, and of the occurrence of the maximum motion, as shown in the following table:—

(Tiflis time.)

Station.	1st prel. tremor.	2nd prel. tremor.	Maximum motion	Duration of 1st prel. tremor.	Distance from Eq. centre.
	h m s	h m s	h m s	m s	
Achalkalaki	3 55 10	3 59 55	4 08 07	4 45	28° 21′
Batum	3 55 30	4 00 22	4 09 12	4 52	29 45
Borshom	3 55 03	3 59 55	4 09 36	4 52	28 30
Derbent	3 54 14	3 58 36	—	4 22	24 58
Schemacha	3 54 20	3 58 55	—	4 35	24 23
	h m s	h m s	h m s	m s	
Mean..........	3 54 51	3 59 33	4 08 58	4 41	27° 11′

Thus the average results are:—

Time of commencement of 1st prel. tremor $=0^h\ 55^m\ 40^s$ (G.M.T.)
„ 2nd „ $=1\ 00\ 22$ („)
Time of occurrence of maximum motion $=1\ 09\ 47$ („)
Duration of the 1st preliminary tremor $=\ 4\ 41$

53. ***Nikolajew***, Russia,*

Marine Astronomical Observatory. 1 mm on the seismogram =0″.016. Commencement$=0^h58.9^m$

The results of the observation with Rebeur-Paschwitz Pendulum, E-W Direction, was as follows.

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* Taken from *Bulletin de la Commission Centrale Sismique Permanente*, Année 1905, Avril-juin. St. Pétersbourg.

Increase of motion (or minimum).	Maximum.	End (or Weakening).	2a
h m	h m	h m	mm
1 04.5	2 17.2	—	29.0
—	2 27.8	—	11.5
—	2 38.9	—	13.5
—	2 49.2	—	9.8
—	3 48.6	—	9.0
—	3 53.8	—	10.0
—	4 02.1	—	8.0
—	4 06.2	—	9.5
—	4 10.8	—	8.1
—	4 21.7	4 32	7.4

54. ***Jurjew*** (Dorpat), Russia.*

Astronomical Observatory, University of Jurjew. (Professor G. Levitsky).

Instrument.	Commencement.	Increase of motion (or minimum).	Maximum.	End (or Weakening.)	2a.
	h m s	h m s	h m s	h m s	mm
Zöllner-Repsold Pendulum E-W.	0 57 54	1 04 00	1 05 05	—	80
		1 12 49	—	—	—
		1 48 41	—	—	—
		2 01 41	—	2 24 19	—
		2 45 12	—	—	—
		3 03 50	—	—	—
		3 22 22	—	—	—
		3 31 36	—	—	—
		3 40 21	—	6 05 00	—

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* Taken from *Bulletin de la Commission Central Sismique Permanente*, Année 1905, Avril-juin. St. Pétersbourg.

Instrument.	Commencement.	Increase of motion (or minimum).	Maximum.	End (or Weakening.)	2*a*.
	h m s	h m s	h m s	h m s	mm
Zöllner-Repsold Pendulum N-S.	0 57 50	1 04 57	1 17 00	—	328
		1 42 09	—	—	—
		2 17 48	—	—	—
		2 36 42	—	2 55 39	—
		3 03 59	—	—	—
		3 36 31	—	5 50.4	

55. ***Belgrade,*** Serbia.

R. Astronomical and Meteorological Observatory. (Prof. M. Nedelkovitch).

The time of Eqke commencement $= 0^{h}\ 57^{m}\ 47^{s}$.

56. ***Krakau,*** Austria-Hungary.

I. R. Astronomical Observatory. (Prof. M. Rudzki.)

The following table, taken from the Krakau earthquake report, gives the elements of motion as recorded by an Omori horizontal pendulum set up in the SE direction, whose natural oscillation period was about 26 sec., and whose magnification was about 10.

	h m	
Commencement	0 58.2	
2nd prel. tremor	1 3.8	
1st max. group	1 14.3 – 23.3 (m)	($2a = 19.5$ mm)
2nd „ „	1 29.5 – 32.1	(„ „ 17.5 „)
3rd „ „	2 0.4 – 1.4	(„ „ 8.0 „)
End portion	2 29.4	
End	3 30.0	

57. ***Jena,*** Germany.*

Seismische Station, Astronomisches Observatorium. (Director, Prof. O. Knopf; Assistant, Dr. O. Eppenstein.)

Wiechert's Pendulum, of the following constants:—

Doppelte Schwingungsdauer bei möglichst kleiner Dämpfung,
T_0 .... $\overset{\text{sec.}}{11.6}$ (EW) ; $\overset{\text{sec.}}{11.2}$ (NS).
Indikatorvergrösserung V .... 171 „ ; 183 „
Maximaler Reibungsausschlag γ.... 0.7 „ ; 0.5 „
Dämpfungsverhältnis ε.......... 4.9 „ ; 4.9 „

Phase of Motion.	Times.	T	$2a$ (EW)	$2a$ (NS)
	h m s	sec.		
Commencement.	0 58 54	ca 1 7–9	0.5 μ 50	0.5 μ 24
2nd Prel. Tremor.	1 06.1	11		140
Long Waves (NS).	1 16.0	12		340
	1 18.7			Over 580 (Here the NS component pointer was thrown out)
Increase of Motion.	1 1.1	(Similar to the first shock)		
	1 5.5	13	45	
Long Waves (EW)	1 16.3	9	140	
Prominent Vibration (EW)	1 23.4	13	790	
” ” ”	1 26.2	11	580	
	1 42.9 – $\overset{\text{m}}{45.9}$	15	160	
Tail (or End Portion)	2 22	15 20 30		
End.	5 30			

58. ***Hamburg,*** Germany.†

Hauptstation fur Erdbebenforschung am Physikalischen Staatslaboratorium. (Dr. R. Schütt.)

Dreifaches Horizontalpendel of Rebeur-Ehlert.

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* *Monatliche Erdbebenberichte der Seismischen Station zu Jena.* April, 1905.

† *Mitteilungen der Hauptstation für Erdbebenforschung am Physikalischen Staatslaboratorium zu Hamburg.* April, 1905.

Phase of motion.	Times.	2a
	h m s	
Commencement.	0 58 14 (Pend. N.)	——
2nd Prel. Tremor.	1 02 23 (Pend. M.)	——
Principal Portion.	1 05 47 („)	——
End.	5 28	——

Pendulum N is directed towards S 15° W.
„ M „ „ E 15° N.

59. ***Padova.*** Italy.[*]

Istituto di Fisica del R. Università di Padova. (Director, Prof. G. Vicentini; Assistants, Dr. R. Alpago and Dr. G. Abetti.)

The motion was recorded by three Microsismografo "Vicentini," A, B, and E, whose instrumental constants were as follows.

(A.) Two horizontal components :—

Length of Pendulum = 10.68 m.
Mass = 400 kg.
Oscillation period = 6.3 sec.
Multiplication = 89.
Velocity of the smoked paper = 20 mm per minute.

(B.) Vertical and two horizontal components :—

Horizontal Components.	*Vertical Component.*
Length of Pendulum = 1.50m.	Length of Spring = 1.32 m.
Mass = 100 kg.	Mass = 45 kg.
Oscillation period = 2.3 sec.	Oscillation period = 1.2 sec.
Multiplication = 129.	Multiplication = 167.

Velocity of the smoked paper = 8.5 mm per minute.

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[*] See Cenno Preliminare sulle Registrazioni dei Microsismografi dell' Istituto di Fisica della R. Università di Padova. 1905.

(E.) Vertical and two horizontal components :—

Horizontal Components.	*Vertical Component.*
Length of Pendulum = 1.50m.	Length of Spring = 1.29 m
Mass = 100 kg.	Mass = 50 kg.
Oscillation period = 2.4 sec.	Oscillation period = 0.8 sec.
Multiplication = 101.	Multiplication = 270.

Velocity of the smoked paper = 15 mm per minute.

Microsismografo A.

Phase of motion.	Time.	Max. 2*a*.	*T*.
Commencement.	$0^h\ 59^m\ 02^s$ (EW)	— mm	— sec.
	1 06 48 (NS)	72	—
	1 06 52 (EW)	75	—
End of first phase.	1 40 30 ca.	—	38
Slow vibration epoch.	1 43 00	—	16-12
End.	4 05 ca.	—	

Microsismografo B.

Phase of motion.	Vertical Component.			Horizontal Component.		
	Times.	Max. 2*a*.	*T*.	Times.	Max. 2*a*.	*T*.
Commencement.	$0^h\ 58^m\ 56^s$	mm	sec.	$0^h\ 59^m\ 00^s$	mm	sec.
	0 59 51	1.7	3.2			
	1 06 27	Small.	4.7	1 06 33	5.2	5.3
				1 17 20		8.5
	1 19 20	Very small	8.0			
				1 24 20		12.5
						20-10
End.	2 28 00			4 05 00		

Microsismografo E.

Phase of motion.	Vertical Component.			Horizontal Component.		
	Times.	Max. $2a$.	T	Times.	Max. $2a$.	T
	h m s	mm	sec.	h m s	mm	sec.
Commencement.	0 58 57			0 58 57		
	1 00 04	5.0		1 01 23	30.2(EW)	
	1 04 ca	End of pend. motion phase.				
				1 12 10		4.0
	1 16 52	Oscillations.	11.0	1 15 ca	Oscillations.	4.8
				1 17 15	„	7.1
	1 21 12	Very small.	9.2			
		Slow oscil.	Varying		Slow oscil.	Varying
End.	2 ca			3 10 ca		

From the above table, we obtain the following mean results :—

Time of Commencement of the 1st Prel. Tremor $= t_1 = 0^h\ 58^m\ 58^s$.
„ „ 2nd „ „ $= t_2 = 1\ 06\ 42$
Duration of the 1st Preliminary Tremor $= y_1 = 7^m\ 44^s$.

60. *Messina,* Italy. Institute of Terrestrial Physics, Royal University (Prof. G. B. Rizzo).

Sismografo "Agamennone" a due componenti; Pendulum Period $=3.9$ sec.

The observation was as follows.*

Phase of motion.	NE-SW Component.			NW-SE Component.		
	Time of Commencement.	T	$2a$	Time of Commencement.	T	$2a$
	h m s	sec.	mm	h m s	sec.	mm
1st Prel. Tremor.	0 59 00	—	—	1 05 24	—	—
2nd „ „	1 06 15	10.9	0.7	1 07 36	6.0	0.7

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* See the *Annuario dell'Anno 1905, Osservatorio di Messina.*

Phase of motion.	NE-SW Component.			NW-SE Component.		
	Time of Commencement.	T	$2a$	Time of Commencement.	T	$2a$
	h m s	sec.	mm	h m s	sec.	mm
Princ. Portion.	1 15 42	—	—	1 15 55	—	—
Max. Phase.	1 25 07	15.6	2.6	1 26 50	16.0	0.6
Next Phase.	1 38 25	—	—	1 39 00	—	—
End	2 02	—	—	1 40	—	—

61. ***Apia,*** Samoa Island.

Samoa Observatory of the Göttingen Academy of Sciences (Dr. F. Linke.) Wiechert's Astatic Pendulum.

The following analysis is taken from the Samoa earthquake report, No. 6, 1905.

Phase of motion.	Time of Commencement.	T	Max. $2a$	
			N-S.	E-W.
	h m		mm	mm
1st preliminary tremor.	1 1.6	(?)	—	--
2nd „ „	1 19.3	17 sec.	0.08	0.09
Large movements.	1 40.	44	0.65	0.65
Maximum vibration.	1 50.	27	0.75	0.55
Tail (End portion).	—	18	—	—
End.	6 00.	—	—	—

62. ***Vieques,*** Porto Rico.

U.S. Coast and Geodetic Survey Magnetic Observatory. (Superintendent, Dr. Tittmann; Observer, P. H. Dike.)

Two Omori horizontal pendulums, recording the EW and NS components, are mounted in the north-east room of the ground floor of the old Spanish Fort "Isabel" on Vieques Island just east of the Island of Porto Rico. The instruments are placed on stone piers laid in cement extending 30 inches below the level of the floor. They are about 130 feet above sea level. The result of the observation was as follows.*

Phase of Motion.	NS Component. (Time of Commencement)	EW Component. (Time of Commencement)
	h m s	h m s
1st Prel. Tremor.	1 10 26	1 10 25
Principal Portion.	1 50 48	1 43 25
Maximum.	2 10 48 ($2a = 1.2$ mm)	2 13 51 ($2a = 1.6$ mm)
End.	3 47 26	3 38 25

Chapter III. Milne Horizontal Pendulum Diagrams of the Kangra Earthquake.

63. ***Milne Horizontal Pendulum Stations.*** The present Chapter contains descriptions of the Milne Horizontal Pendulum Seismograms obtained at the following 19 stations:—Shide; Kew; Liverpool (Bidston); Edinburgh; Paisley; San Fernando; Wellington; Christchurch; Mauritius; Cape of Good Hope; Toronto; Victoria, B.C.; Baltimore; Calcutta; Kodaikanal; Bombay (Colaba); Bairût; Ponta Delgada; Honolulu. The analysis has been made of the photographic copies, except in the cases of the 3 last places whose diagrams I have not received. The reproduction of the registers are given in Pls. XVIII to XXII, the *Publications*, No. 23.

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* Reproduced from Professor Reid's paper given in the *Terrestrial Magnetism and Atmospheric Electricity.*

The Milne horizontal pendulums are, according to the instructions from the British Association, usually so placed that the boom is in the meridian or points N–S, the natural oscillation period being about 15 sec. The magnification with respect to the horizontal earthquake motion is 6 to 7 times.

64. ***Utility of Milne Horizontal Pendulum.*** The Milne Horizontal Pendulum has rendered an invaluable service to the development of Seismology, a science practically founded on its modern basis by Professor John Milne, who pursues the subject with indefatigable energy and zeal. The instrument is simple in construction, and enables us to see some interesting features in the earthquake motion, which are not so obviously shown by other seismographs. In the present case, the records obtained at 5 British stations, San Fernando, Christchurch, Wellington, and some other places are very satisfactory.

65. ***Time of Occurrence and Duration.*** The times of occurrence of the different phases and the total duration of the Kangra earthquake of April 4, 1905, observed at the different stations, as given in Professor Milne's Circular, No. 13, are contained in the following table.

TABLE VIII. Indian Earthquake of April 4, 1906, observed with Milne Horizontal Pendulums.

(Extract from Professor Milne's Circular, No. 13.)

Station.		P. T. Commence.	Max.	Max. Amplitude.	Duration.
Shide.	(*B*)	1^{h} $1^{m}.0$	1^{h} $30^{m}.0$	$15.0^{mm}=a$	3^{h} 55^{m} (2nd max. $1^{h}54^{m}$ later)
,,	(*C*)	1 6.2	1 22.7	13.0	3 45 (2nd max. 2^{h} 9^{m} & 2^{h} 14^{m} later)

(*B*: period 25 sec.; *C*: period 20 sec.)

Station.	P. T. Commence.	Max.	Max. Amplitude.	Duration.
	h m	h m	mm	h m
Kew Observatory.	1 0.2	1 29.2	15.3	3 48
Liverpool Ob., Bidston.	0 58.8	1 30.6	11.6	4 22
Royal Ob., Edinburgh.	1 0.0	1 31.5	16.0	3 43
The Coats Ob., Paisley.	1 0.4	1 30.7	>14.0	3 40
San Fernando.	1 2.5	1 34.0	8.75	3 45½
Ponta Delgada, St. Miguel, (Azores.)	1 1.0	1 54.5	2.3	2 32½
Royal Ob., Cape of G. H.	1 2.0	1 46.0	3.0	2 10
Alipore Observatory.	0 52.	?	?	3 39
Bombay (Colaba).	0 52.9	—	—	4 19.6
Kodaikanal.	0 55.6	—	>22.0	3 36
Batavia.	0 58.6	1 1.9	7.0	3 —
Baltimore.	1 15.0(?)	2 10.0	3.0	
Beirût, Syria.	0 58.0	1 24½	18.5	3 59
Toronto.	1 14.0(?)	1 54.3	4.0	3 25.8
Victoria, B. C.	1 14.0	1 51.1	6.3	3 26.3

In the analysis of the Milne horizontal pendulum record, the period of vibration has been measured, in several cases, by the use of a magnifying lens. The $2a$ always denotes the motion as actually traced on the photogram.

66. ***British Stations and San Fernando.*** For the sake of comparison let us first describe the seismographs obtained at the 5 British stations of Shide, Kew, Bidston, Edinburgh, and Paisley, and the Spanish station of San Fernando. The records at these places are given in Pls. XVIII and XIX, the *Publications*, No. 23.

67. ***Shide,*** Newport, Isle of Wight, England.

(Professor J. Milne, F.R.S. Assistant, S. Hirota).

The earthquake was recorded by two instruments *B* and *C*, of the following constants :—

B. Period = 25 sec. 1° turn = 9 mm.

C. Period = 20 sec.

C pendulum is without a calibrating screw.

B records N. S. motion, while *C* records E.W. motion.

Horizontal Pendulum B. Commencement = 1^h 1.0^m In the strongest part, $T=26.0$ sec. (pendulum oscillations), the max. trace of 22 mm having occurred at 1^h 30.0^m. The motion was more or less active till 2^h 34.5^m, becoming thereafter very small, till the commencement of the W_2 group.

The latter first appeared at 3^h 4.6^m and the max. trace of 2.5 mm was gradually reached at 3^h 23.4^m; there being in the interval altogether 6 max groups, at an average interval of about 3^m 52^s. The W_2 motion may be regarded as having lasted about 54^m.

A slight thickening of the line at about 4^h 37^m may correspond to the W_3 motion.

Hor. Pendulum C. Commencement = 1^h 6.2^m. In the strongest portion, $T=21$ sec. (pendulum oscillations), the max. trace of 27 mm having occurred at 1^h 22.7^m. The motion was more or less active till 2^h 40^m, becoming thereafter much smaller.

The diagram is somewhat different from that described above, especially in the W_2 group, which first began at 3^h 8.6^m. For the next 12^m 24^s, the motion was small and doubtful. Then, at 3^h 20^m 24^s, there occurred a small maximum (which is marked ***a*** in the diagram). For the next 27^m the motion was well defined and consisted of a number of max. movements (marked *b, c, d, e, f*). These small groups, *a* to *f*, can be identified in the B-pendulum record, although the amplitudes differ much in the two diagrams. The greatest $2a$ of 3.6 mm took place at $3^h\ 38.7^m$. For the next $14^m\ 30^s$, the motion was much smaller but nearly constant, the W_2 group having lasted altogether $1^h\ 6^m$.

The W_3 group occurred at about $4^h\ 32.5^m$.

68. ***Kew,*** England. National Physical Laboratory, Kew Observatory. (Director, R.T. Glazebrook, D. Sc., F.R.S.; Superintendent, C. Chree, LL. D., F.R.S.; Observer, E. G. Constable.)

Commencement $= 1^h\ 0.2^m$. Total Duration $= 3^h\ 48.1^m$.

1st and 2nd Preliminary Tremors. The entire Duration $= 13.6^m$. For the first 4.5^m the motion was very small. Then the motion increased slightly and remained nearly constant for the next 4.2^m During the remaining 4.9^m the motion was again slightly larger, there being 4 maximum groups, which occurred at an average interval of $1^m\ 38$.

Principal and End Portions. For the first 1.5^m the motion gradually swelled up to a max. $2a$ of 3.5 mm, being the result of the proper oscillations of the pendulum. For the next 1.5^m the motion was small. For the next 4.0^m the motion was larger, the max. $2a$ of 4.4 mm occurring at the commencement.

For the next 2.6^m the motion was smaller; there being several minimum epochs, probably due to the appearance of slow vibrations, which prevented the pendulum from swaying into the proper oscillation. The time of commencement of this phase was 20.2^m after the beginning of the earthquake.

Then, at $1^h\ 23.2^m$, there appeared a maximum group, which lasted 5.9^m and was composed of 2 subdivisions. This was followed by a minimum, and then by the absolute maximum group, which lasted 3.0^m and whose greatest $2a$ of 30.6 mm occurred at 1^h 29.2^m.

Thereafter the motion was much smaller and remained for the next 28.6^m on the whole constant; there being 7 max. groups, whose average interval was 4.1^m and of which the 3rd one had the greatest $2a$ of 13 mm. For the next 7.0^m, the motion was smaller:—max. $2a=3.0$ mm. For the next 21.8^m the motion was again larger (max. $2a=8$ mm); there being a series of maximum groups. (The end of this epoch was at 2^h 28.2^m.) The subsequent motion was much smaller (max. $2a=2.0$ mm), the amplitude remaining for the next 50^m nearly constant. For the next 30^m the motion was small, being nearly the same as in the 2nd stage of the preliminary tremor.

W_2. The W_2 motion began at 3^h 36.9^m, when the motion became larger again and remained active for the next 27^m, comprising a number of max. groups, The greatest $2a$ was 2.6 mm.

69. ***Bidston (Liverpool),*** England. Liverpool Observatory. (Director, W. E. Plummer.) Time of Commencement$=1^h$ 0^m 36^s. Total Duration$=4^h$.

The motion during the successive epochs was as follows:—

(i) For 3.1^m: small, but distinct.
(ii) „ 4.6^m: larger, max. $2a=1.0$ mm.
(iii) „ 2.9^m: max. $2a=2.0$ mm, occurred at the commencement.
(iv) „ 6.0^m: there were 5 small maximum groups, the 3rd and 4th having the max. $2a$ of 3.0 mm. $T=21.2$ sec.
(v) „ 6.7^m: the motion gradually reached a max. $2a=4.5$ mm, there being, however, among it some alternations of max. and min. $T=19.2$ sec.

So far the motion lasted 23.3^m and may be regarded as roughly corresponding to the 1st and 2nd preliminary tremors and the 1st and 2nd phases of the principal portion.

(vi) For 3.7^m: there was a single group, the motion gradually reaching a max. $2a=12.6$ mm, and again gradually diminishing to a minimum. This epoch, which commenced at $1^h\ 23^m\ 54^s$, probably corresponds to the 3rd phase of the principal portion, the maximum motion having occurred at $1^h\ 28^m\ 54^s$. $T=18.3$ sec.

(vii) For 3.6^m: there were 4 max. groups, of which the 3rd had the max. $2a$ of 11.4 mm. $T=19.4$ sec.

(viii) For 3.3^m: there was a single group, gradually reaching the absolute max. $2a=20.0$ mm, at $1^h\ 29^m\ 48^s$.

(ix) For 30.8^m: the motion remained on the whole constant (max. $2a=11.0$ mm), there being a series of max. groups. At the middle of this epoch, T was 18.8 sec.

(x) For 13.4^m: there was not much alternation of max. and min. groups, the $2a$ diminishing to 1.9 mm; $T=18.2$ sec.

The subsequent motion was much smaller, and may be taken as the *end portion*:—$T=18.2$ sec. Among a number of max. groups, there were two well defined ones, as follows:—

(1) $2a=2.0$ mm, between $2^h\ 22^m\ 0^s$ and $2^h\ 35^m\ 12^s$;
(2) $2a=1.6$ „ , „ 2 39 36 and 2 49 36.

W_2. The W_2 motion appeared at $3^h\ 28^m\ 58^s$, there being, for the next $13^m\ 18^s$, a continuous max. group, till $3^h\ 44^m\ 6^s$. The max. $2a$ of 4.2 mm occurred at $3^h\ 37^m\ 48^s$; $T=17.5$ sec. The subsequent motion was smaller. The period T was 21.2 sec. in the epoch corresponding to the earlier part of the 2nd preliminary tremor, and 17.5 sec. in what may correspond to the 3rd phase of the principal portion of the W_2 motion. The 6 other values of the period given above varied between 18.2 and 19.4 sec., the average being 18.7 sec., which evidently represents the oscillation period of the pendnlum.

70. *Edinburgh,* Scotland. Royal Observatory. (Director, Dr. R. Copeland. Observer, Thomas Heath.)

Time of Commencement$=1^h\ 0^m\ 0^s$. Total Duration$=3^h\ 43^m$.

The Edinburgh diagram is very much similar, almost group for group, to that obtained at Kew. The instruments at these two stations had probably nearly equal oscillation periods. The movements in the successive stages of motion were as follows :—

(i) For 6.5^m: the motion was very small.
(ii) „ 6.0^m: the motion rapidly reached a max. $2a$ of 4.0 mm, at 2.0^m from the commencement, thence being gradually reduced to a minimum.
(iii) „ 5.2^m: a max. $2a$ of 5.5 mm was gradually reached at 3.0^m from the commencement, thence being again reduced to a minimum.
(iv) „ 5.0^m: there was an ill defined max. group, $2a=3.5$ mm.

So far the motion altogether lasted 22.7^m and corresponds to the 1st and 2nd preliminary tremor and the 1st and 2nd phases of the principal portion. The following three epochs, (v) to (vii), which began at $1^h\ 22.^m6$, and together lasted 9.7^m probably corresponds to the 3rd phase of the principal portion.

(v) For 2.2^m: there was a single max. group, $2a=10.0$ mm.
(vi) „ 2.9^m: there were two max. groups, each having max. $2a$ of 18.0 mm.
(vii) „ 4.6^m: the motion was most active and consisted of two main groups, the 2nd having max.$2a$ of 32 mm, which occurred at $1^h\ 31.5^m$.
(viii) „ 21.0 m: the motion became much smaller (max. $2a=8.0$ mm),

there being a series of about 11 max. groups, whose average interval was 2.1^m.

(ix) For 9.5^m: there were 5 max. groups (max. $2a=6.0$ mm), with an average interval of 1.9^m. The 1st 3 groups are nearly amalgamated into one continuous maximum.

(x) „ 7.3^m: there was a continuous max. group, max. $2a=5.0$ mm.

(xi) „ 2.0^m: a small max. group, $2a=3.0$ mm.

(xii) Then followed a max. group, whose max. $2a=6.0$ mm occurred at $2^h\,13.4^m$.

(xiii) The subsequent max. groups were more or less active (max. $2a=2.5$ mm) up to $2^h\,39.9^m$.

(xiv) For 34.3^m: the motion was on the whole constant; max. $2a=1.4$ mm.

(xv) „ 33.3^m: the motion was smaller, and nearly constant; max. $2a=1.0$ mm.

W_2. The W_2 motion appeared at $3^h\,46.9^m$, forming a max. group for about 13.3^m; max. $2a=2.0$ mm.

71. ***Paisley***, Scotland.

The Coats Observatory. (Superintendent, David Crilley.)

Time of Commencement $=1^h\,0.0^m$. Total Duration $=3^h\,10^m$.

1st Preliminary Tremor. Duration $=8.3^m$. The motion was very small during the first 4.1^m.

The subsequent movements were as follows.

(i) For 11.3^m: the motion was large; max. $2a=3.7$ mm.

(ii) „ 4.6^m: the motion was again smaller.

(iii) „ 13.7^m: the most active part of motion, commencing at $1^h\,23.9^m$. The max. group, ($2a=32.5$ mm,) occurred at $1^h\,31.2^m$.

(iv) „ 12.2^m: the motion was smaller, but still active; max. $2a=10$ mm.

(v) „ 29.6^m: the motion was nearly constant; max. $2a=5.0$ mm.

Thereafter the motion became again smaller, being, however, more or less active till 3^h 18^m.

W_2. The W_2 motion began at 3^h 48.4^m, there being, during the next 18.5^m, two main groups, $2a$ of the first being 1.8 mm.

72. ***San Fernando,*** Spain.

Instituto y Observatorio de Marina. (Director, Capitán de Fragata Tomás de Azcárate.)

Time of Commencement = 1^h 2.5^m. Total Duration = 3^h 46^m.

The San Fernando seismogram is much similar to those obtained at Edinburgh and Kew; especially, between the commencement of the 3rd phase of the principal portion and about 2^h 30.7^m, and also in the *end portion*, the San Fernando and Kew diagrams are almost identical group for group.

The motion was very small during the first 9.2^m. Then, at 1^h 12.3^m there took place the first max. group ($2a$ = 2.0 mm). What may be regarded as the 3rd phase of the principal portion began at 1^h 27.1^m. The times of occurrence and the $2a$'s of the successive maximum movements are given in the following list.*

Time.	Max. $2a$.	Time.	Max. $2a$.
h m 1 16.0	mm 2.50	h m 1 45.5	mm 5.25
1 23.0	3.75	1 57.5	6.25
1 26.0	4.25	2 1.5	5.50
1 29.0	8.75	2 6.5	4.25
1 34.0	8.75	2 14.0	4.25
1 36.0	6.75	2 23.0	2.25
1 39.0	7.25	3 38.5	2.00
1 41.0	6.25	3 46.0	1.50
1 42.0	6.25		

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* This list was kindly furnished by Cap. Azcarate.

W_2. The W_2 motion began at 3^h 30.7^m, lasting for about 20^m. The max. $2a$ was 3.7 mm.

73. *New Zealand Records.*

The seismograms obtained at Wellington and Christchurch are reproduced in Pl. XXI, the *Publications*, No. 23. Some of the more prominent maxima identified in the two records are marked by the letters *a*, *b*, *c*,....*x*, *y*, *z*.

74. Wellington, New Zealand. (Observer, G. Hogben, M. A.)

Time of Commencement$=1^h$ 9.8^m. Total Duration$=3^h$ 40^m.

For the first 10.0^m, the motion was extremely small. At 1^h 17.5^m there took place a very slight maximum, the motion for the next 2.2^m being again small. Then took place the first well defined maximum motion. This, marked *a*, and the subsequent maxima, marked *b*, *c*,....*y*, *z*, were as follows:—

a. ....1^h 19.8^m, $2a=1.2$ mm
b. 1 25.6 , $2a=2.1$
c. 1 26.9 , $2a=1.1$
d. 1 29.9 , $2a=1.8$

The epoch between the commencement and *d*, whose duration was 20.1^m, probably corresponds to the 1st preliminary tremor. For the next 13.6^m, the motion consisted of a series of small maximum groups, the greatest being the following:—

e. ....1^h 41.8^m, $2a=3.0$ mm

Judging from the Christchurch diagram, the subsequent portion seems to be made up of long period vibrations, and the next 17.1^m probably corresponds to the 1st and 2nd phases of the principal portion. For the first 8.9^m of this portion the motion was small, the max. $2a$ being 5.0 mm. For the remaining 8.2^{m}, the motion was much greater, the two last maxima being as follows :—

f.....1^{h} 57.6^{m}, $2a=13.6$ mm
g. 1 59.9 , $2a=11.6$ „

For the next 14.8^{m}, which probably corresponds to the 3rd phase of the principal portion, the motion consisted essentially of 2 groups of maxima, which lasted 5.6 and 7.0^{m} respectively, the two being separated by a minimum whose duration was 2.2^{m}. The 1st group consisted of 3 sub-maxima, whose first and 3rd ones were as follows :—

h.....2^{h} 2.2^{m}, $2a=23.0$ mm
i. 2 4.9 , $2a=21.0$ „

The 2nd group also consisted of 3 maxima, whose first two were as follows :—

j.... 2^{h} 10.1^{m}, $2a=21.0$ mm
k. 2 11.9 , $2a=26.0$ „

Thereafter the motion became much smaller and consisted, for the next 13.2^{m}, of 7 max. groups, the first of which has a max. $2a$ of 6.8 mm : the times of occurrence of the maximum movements being as follows :—

l. ....2^{h} 16.8^{m} *p*.....2^{h} 24.5^{m}.
m. 2 18.8 *q*. 2 26.5
n. 2 20.5 *r*. 2 27.3
o. 2 21.5

***W_2*.** The W_2 motion appeared at 2^{h} 29.3^{m} and continued for 15.4^{m}, there being two well defined max. groups, as follows :—

s.....2^{h} 29.3^{m}, $2a=5.0$ mm ;
t. 2 34.8 , $2a=2.0$ „ .

For the next 29.5^{m}, the motion consisted of a series of detached maxima (greatest $2a=2.4$ mm), some of which occurred as follows :—

u.....$2^h\ 54.1^m$ w.....$3^h\ 1.9^m$
v. 2 56.1 x. 3 12.6

For the next 14.0^m, the motion was small.

„ „ 11.3^m, there was a series of max. groups, of which the greatest was the following:—

y.....$3^h\ 35.7^m$, $2a = 2.0$ mm.

For the next 7.5^m, the motion was small.

„ „ 10.0^m, there was a max. group:—

z.....$3^h\ 50.0^m$, $2a = 1.2$ mm.

Thereafter the motion became much smaller. At $4^h\ 36.6^m$, however, there appeared a slight but distinct group, consisting of 2 maxima: $2a = 0.7$ mm. These lasted about 6^m, the subsequent motion being very small and doubtful.

75. ***Christchurch,*** New Zealand. Magnetic Observatory. (Observer, Henry F. Skey, B. Sc.)

Time of Commencement $= 1^h\ 10.0^m$. Total Duration $= 3\frac{1}{2}^h$

The diagram, which is very distinct, is on the whole similar to that obtained at Wellington. The successive maxima were as follows.

Maximum.	Time of Occurrence.	$2a$.	Maximum.	Time of Occurrence.	$2a$.
	h m	mm		h m	mm
a	1 17.5	1.7	g	2 5.5	9.6
b	1 23.6	2.0	h	2 8.0	17.0
c	1 25.9	3.9	i	2 13.0	14.2
d	1 30.1	5.0	j	2 17.4	9.5
e	1 44.5	3.0	k	2 20.0	16.4
f	2 2.4	14.0	l	2 24.2	9.0

Maximum.	Time of Occurrence.	$2a$.	Maximum.	Time of Occurrence.	$2a$.
	h m	mm		h m	mm
m	2 26.3	10.0	*t*	2 45.7	2.9
n	2 28.9	5.4	*u*	3 4.4	1.3
o	2 30.4	6.3	*v*	3 8.3	3.9
p	2 32.6	5.0	*w*	3 15.1	2.1
q	2 34.7	2.1	*x*	3 22.2	1.7
r	2 35.8	3.2	*y*	3 53.1	1.2
s	2 38.8	6.1	*z*	4 11.2	0.9

Notes to the above table :—

Between the commencement of the earthquake and (*a*), the motion was extremely small.

Between (*a*) and (*d*), both inclusive, there were 6 maximum groups, very nearly equidistant, the average interval being 2.5^m.

For some interval after (*e*), T=28.0 sec.

Other measurements of the period were as follows :—

Between (*f*) and (*h*) : T=18.0 sec.
" (*h*) and (*k*) : " =16.3 "
(*s*) . . . . : " =15.5 "

The last three determinations give the average value of 16.6 sec., which must be the oscillation period of the pendulum. The period of 28 sec., for (*e*), was probably that of the earthquake motion at that particular epoch.

76. ***Mauritius.*** Royal Alfred Observatory. (Director, T. F. Claxton, F.R.A.S. Assistant Director, A. Walter.)

The seismograph had two components, EW and NS, the sensibilities to tilting being as follows :—

NS Component: 1 mm=$0''.29$;
EW „ : 1 mm=0.26

Time of Commencement=0^h 58^m 54^s. Total Duration=2^h.

1st Preliminary Tremor. The motion was very small, the duration being as follows:—

NS......8.0^m; EW......8.3^m.
Mean duration=8^m 9^s.

2nd Preliminary Tremor. The duration was as follows:—

NS......9.4^m; EW......8.6^m.
Mean duration=8^m 59^s.

Then there took place, in the NS component, a displacement of the pendulum towards the north; the EW pendulum remained in position. The subsequent record is very obscure; the motion becoming small after 5^h 52^m.

77. Cape of Good Hope. (Pl. XXI, the *Publications*, No. 23.) Royal Observatory (Director, Sir David Gill, K. C. B., F. R. S.)

Time of Commencement=1^h 2.5^m. Total Duration=2^h 6^m.

The commencement was not quite distinct.

1st Preliminary Tremor. Duration=9^m 57^s.

2nd Preliminary Tremor began with a max. group (2=4.0 mm), and remained for the next 23.3^m smaller than 1.5 mm. Then, at $1^h 36.2^m$, the motion became most active (max. $2a=5.2$ mm), continuing so for 21.8^m.

Thereafter the motion became smaller, remaining nearly constant for the next 24.3^m (max. $2a=2.0$ mm). The subsequent motion gradually diminished; very slight but distinct movement being indicated for further 30^m.

W_2. What may correspond to the W_2 motion, consisting of a very slight maximum, appeared at 3^h 8.3^m,

78. ***Toronto,*** Ontario, Canada. (Pl. XXII, the *Pubilcations*, No. 23.) Met. Observatory (Directior, R. F. Stupart, F. R. S. C).

Time of Commencement$=1^h\ 6.6^m$. Total duration$=3^h\ 33^m$.

The diagram is not very distinct.

1st Preliminary Tremor. During the first 7.6^m, the mortion was very slight and doubtful. The first maximum group occurred at $1^h\ 14.2^m$, the $2a$ being 1.2 mm, and lasting for 3.9^m.

For the next 8.8^m, the motion was very small.

„ „ 22.7^m, „ was larger ($2a=1.8$ mm).

Then, at $1^h\ 49.7^m$, there began the most active portion, which lasted 20.4^m; max. $2a=6.6$ mm.

For the next 38.5^m, the motion was smaller but more or less active, thence gradually decreasing.

79. ***Victoria,*** B.C., Canada. (Pl.XXII, the *Publications*, No .23.) Meteorological Observatory (Superintendent, E. Baynes Reid).

Time of Commencement$=1^h\ 6.8^m$. Total duration$=3^h\ 33^m$.

For the first 37.0^m, the motion was small :— $2a=2.0$ mm.

For the next 11.3^m, the motion was most active :—$2a=$ 12.4 mm.

For the next 22.6^m, the motion remained nearly constant :— $2a=2.8$ mm.

The motion then gradually diminished.

The diagrams at Toronto and Victoria are similar in the earlier part of the motion.

80. ***Baltimore,*** Md., U.S.A. (Prof. Harry Fielding Reid.)

Time of Commencement$=1^h10^m30^s$. Total Duration$=3^h40^m$.

The commencement is very indistinct, the indication becoming definite first at $1^h\ 15^m\ 48^s$.

The total duration of the 1st and 2nd preliminary tremors $=42^m\ 36^s$ (?); $2a=2.0$ mm.

The most active part began at $1^h\ 53^m\ 6^s$ and remained nearly constant for $20^m\ 24^s$, there being 6 maximum groups, the largest of which ($2a=6.0$ mm) occurred at $2^h\ 10^m$.

The subsequent motion was much smaller (max. $2a=2.5$ mm) and remained on the whole nearly constant for the next $15^m\ 30^s$; there being 4 max. groups occurring at an average interval of $5^m\ 10^s$. These 4 groups comprised altogether 64 complete (pendulum) oscillations, giving an average period of 15.2 sec. Thence the motion became again much smaller.

The duration of the principal portion was about 49^m.

The end of motion was at about $4^h\ 50^m$.

W_2. What may correspond to the W_2 motion occurred at about $3^h\ 13^m\ 30^s$; $2a=0.8$ mm.

81. ***Calcutta,*** India. (Pl. XX, the *Publications*, No. 23).

Alipore Observatory. (Director, G. W. Küchler, Assistant Meteorological Reporter).

The motion began very gradually, the duration of the preliminary tremor being about $3^m\ 9^s$. For the next $15^m\ 18^s$, the motion was very active and the boom end swang through the whole width of the photographic paper. For the next $13^m\ 24^s$, the motion was still active, but consisted in 5 max. groups. Then the motion gradually diminished till about $8^h\ 38^m$ (Calcutta time). Thereafter it remained very small.

W_2 began at $9^h\ 37^m$ (Calcutta Time), or at $2^h\ 56^m$ after the commencement of the earthquake. For the 1st 13^m, the motion was small and doubtful. For the next $16^m\ 30^s$, it was well defined, the last group having a max. $2a$ of 1.8 mm. After 4^m, during which the motion was small, there took place a small max. group ($2a$=1.0 mm), lasting 4.6^m. This latter may correspond to W_3.

82. *Kodaikânal,* Madras, India.

Solar Physics Observatory. (Director, C. Michie Smith.)

The instrument had evidently a great friction, and the record is not satisfactory.

Commencement=6^h 16.3^m (Madras Time), or 0^h 55.6^m (G.M.T.)

Total Duration=3^h 36^m.

The *1st Preliminary Tremor* lasted 3^m 55^s, the max. $2a$ being 1.8 mm. For the next 2^m 19^s there were two max. groups, the first having the max. $2a$ of 22.6 mm. Then the index strack sideways and the record was not given till 8^h 13^m (Madras time), when the pointer was brought back by hand and put into the working condition again. The motion was distinctly shown till 8^h 33.2^m (Madras time), the max. $2a$ during this interval being about 1 mm. Thereafter the motion became very slight, and for the next 58.5^m, there was no very great variation, showing a series of very small max. groups.

A small maximum group, similar in form to that in the Liverpool and Edinburgh diagrams, occurred at 8^h 57.7^m (Madras time). This may correspond to W_2, but the record is doubtful and the above may be a time signal.

83. *Colaba,* Bombay. (Pl. XX, the *Publications*, No. 23.)

Government Observatory. (Director, N.A.F. Moos.)

Commencement=0^h 52.9^m. Total Duration=4^h 19.6^m.

The diagram is on the whole similar to the Alipore one.

After the preliminary tremor, which lasted 3^m 31^s, the motion became suddenly large and continued very active for $8^m 42^s$. During the next $9^m 42^s$, it consisted of a number of separate maximum groups. Thereafter the motion gradually diminished.

The identification of W_2 and W_3 is doubtful.

84. ***Honolulu,*** T.H.[*] (Observer, S.A. Deel. Compiler, A.E. Burbank.)

Commencement........	$1^h 04.^m6$	
2nd Group	1 08. 7	
Long Waves..........	1 15. 0	
Maximum	1 35. 2	(2.5 mm)
	1 47. 2	(4.5 „)
	1 55. 5	(8.2 „)
End	5 20. 0	

Chapter IV. Velocity of Propagation of the 1st Preliminary Tremor.

85. ***Places situated approximately on Same Great Circles of the Earth passing through the Origin of the Earthquake.***

The origin of the earthquake under consideration is situated among the great Himalayan mountain range, in the middle of the extensive continent of Asia. A question which naturally presents itself in connection with the transit velocity is whether or not the latter differed along the various routs of radial propagation. With a view of finding out such a relation, if possible, I have divided the different observing stations into a number of groups, as follows.

Group 1. Tacubaya, Toronto, Victoria, B.C., Colaba, (Bombay),

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[*] Reproduced from Professor Milne's Circular, No. 13.

Kodaikanal (Madras). The great circle connecting Tacubaya with the earthquake origin passes very nearly through the North Pole: the seismic waves being propagated through the *flat regions* of Siberia and Canada and the depressed tract forming the Arctic basin. The azimuth of Tacubaya with respect to the origin, or the direction of the above mentioned great circle at the latter, is N 4°36′ W.

Toronto and Victoria, B.C., are situated slightly out of the same circle. Colaba (Bombay) and Kodaikanal (Madras) lie nearly on the southern prolongation of the meridian through the origin.

Group 2. Great Britain, North Germany, Batavia. Great Britain and North Germany lie approximately on a great circle passing through the origin, the seismic waves reaching these places after traversing through the *flat grounds* of the Transcaspian and South Russian districts. The stations belonging to this group are as follows.

Great Britain :—Kew, Edinburgh, Birmingham, Shide, Liverpool, Paisley.

North Germany :—Hamburg, Potsdam, Leipzig, Göttingen, Jena. Batavia lies nearly on the southern prolongation of the same great circle.

Group 3. South Austro-Hungary, North Italy; Nicolajew; Calcutta, Taungoo, Christchurch and Wellington (New Zealand); Rio de Janeiro; Ponta Delgada (Azores); Taschkent, Tiflis. South Austro-Hungary and North Italy lie nearly on the same great circle through the origin, which coinsides with the Caucasus Range; the paths of the earthquake propagation being in this case through *mountainous regions.* Azores, Tiflis, and Taschkent are also not much away from the same circle, while Calcutta, Taungoo (Burma), New Zealand, and Rio de Janeiro are roughly on the south-eastern prolongation of the latter.

Group 4. Taschkent, Krakau, Strassburg, Calcutta.

Group 5. Taschkent, Jurjew (Dorpat), Upsala; Porto Rico; Batavia. The great circles on which the stations of these two groups are situated are not far from those for the 2nd and 3rd groups.

Group 6. Japan. The seismic waves reached Japan by paths across plateau and continent, the great circle connecting the origin with Tokyo passing through Tibet, the valley of the Hoang Ho, southern extremity of Korea, and the western part of the Main Island of Japan. The stations of this group are:—Tokyo, Mizusawa, Kobe, Osaka, and Taihoku.

Group 7. Tiflis; Belgrade; Ischia, Messina; Querce, Ximeniano, Quarto-Castello (Florence); Rocca di papa; San Fernando; Calcutta, Taungoo; Wellington, Christchurch (New Zealand). All these places are situated approximately on one and the same great circle; the first 9 being towards WNW, and the remaining 4 towards ESE, of the earthquake origin.

Group 8. Washington, Cheltenham, Toronto, Tiflis; Kodaikanal, Batavia. All these places are approximately on one and the same great circle through the origin, the first 4 being to the NNW, and the remaining 2 to the SSE, of the latter.

Group 9. Honolulu (Hawaii), Irkutsk.

Group 10. Formosa, Bairût (Asia Minor).

Single Stations. Those places which do not make groups lying on a great circle through the origin are as follows:—Manila, Mauritius, Cape Town, Baltimore.

86. *Methods of Calculating the Velocities of Earthquake Propagation.* * There are two distinct methods of the velocity calculation, as follows:—

(A) "Direct Method," in which the transit velocity is obtained by dividing the epicentral distance of a station by the difference between the times of occurrence of a particular phase of motion at the latter and the origin of disturbance. Thus, if x' be the epicentral distance of a place, and t' and t_0 be respectively the times of occurrence at the latter and the origin, we have :—

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* See the *Bulletin of the Imperial Earthquake Investigation Committee*, Vol. I, No. 1.

$$\text{Velocity}=\frac{x'}{t'-t_0}.$$

(B) "Difference Method," in which the velocity is obtained by dividing the difference of the epicentral distances of any two stations by the difference of the times of occurrence of a given phase of motion at these stations. Thus, if x' and t' have the same meaning as before and if x'' and t'' be the corresponding quantities at a second place, we have :—

$$\text{Velocity}=\frac{x'-x''}{t'-t''}=\frac{\delta x}{\delta t}.$$

The "difference method" gives always a higher value of the velocity than the "direct method"; the discrepancy, which becomes smaller with the increase of the epicentral distance, being markedly shown up to the distance of about 40°.

In the "difference method," we have no need of ascertaining the time of occurrence at the origin of disturbance; the inaccuracy about the position of the epicentre being also avoided in a great measure, provided those stations which are taken for combination lie on one and the same great circle passing through the epicentre, on one side of which they are all situated.

The velocities corresponding to the commencement of the different phases of the earthquake motion will be denoted in subsequent §§ by the same symbols as in my former papers, namely, as follows :—

v_1........Velocity of the 1st preliminary tremor;
v_2........ " 2nd " " ;

v_3........ Velocity of the 1st Phase, Principal Portion;
v_4........ „ 2nd „ „ ;
v_5........ „ 3rd „ „ ;
v_6........ „ 4th „ „ ;
v_7........ „ 5th „ „ ;
v_8........ „ End Portion (8th Section).

In the velocity calculations, the epicentral distance (x) has been taken to denote the *arcual* length between the earthquake origin and a given station.

I give next the values of the transit velocity v_1, for the different groups of stations, deduced according both to the "direct method" and the "difference method"; all the necessary data being contained in Table I. For the "direct method" calculation, the time of earthquake occurrence at the epicentre has been assumed to be $t_0 = 0^h 49^m 48^s$ G.M.T.

87. ***Group 1. Tacubaya; Toronto; Victoria, B.C.; Colaba (Bombay); Kodaikanal (Madras).***

v_1 calculated by "Direct Method."

Station.	x	t_1	$t_1 - t_0$	v_1
Tacubaya	128° 47′	$1^h 11^m 25^s$	$21^m 37^s$	km/sec. 11.03
Toronto, Victoria, B.C.	99 36	1 06 42	16 54	10.91
Colaba	13 28	0 53 08	3 20	7.48
Kodaikanal	21 35	0 55 48	6 00	6.66

The mean transit velocity along the rout approximately *through the North Pole*, deduced from the observations at Tacubaya, Toronto, and Victoria, was, for $x = 114°\ 12'$, about 10.97 km per sec. The time of commencement given by the Kodaikanal register seems to be somewhat too late.

v_1 calculated by "Difference Method."*

Combination of Stations.	δx	δt_1	v_1
Tacubaya – {Toronto Victoria	29° 11′	$4^m 43^s$	11.45 km/sec.
„ – Colaba	115 19	18 17	11.68
{Toronto Victoria – „	86 08	13 34	11.76

The values of v_1 here obtained agree well with each other and vary between 11.45 and 11.76 km per sec., giving the average velocity of **11.63** km per sec. This is about 0.7 km greater than the value found by the "direct method," and may be regarded as the velocity of the 1st preliminary tremor when passing through the earth's crust near the *North Pole.*

88. *Group 2. Great Britain, North Germany; Batavia.*

v_1 calculated by "Direct Method."

Station.	x	t_1	$t_1 - t_0$	v_1
Great Britain. {Shide, Kew, Paisley, Liverpool, Birmingham, Edinburgh.	58° 54′	$1^h\,00^m\,24^s$	$10^m\,36^s$	km/sec. 10.30
North Germany. {Hamburg, Leipzig, Potsdam, Göttingen, Jena.	50 50	0 58 43	8 55	10.56
Batavia.	42 35	0 58 33	8 45	9.01

As remarked below, the time given by the Batavia register seems to be a little too late. The results obtained for the two groups of the British and North German stations are practically identical, the mean velocity being **10.36** km per sec., for $x=54^\circ$ 45′ The path of the earthquake propagation was, in these cases, almost entirely across flat regions.

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* Kodaikanal excluded.

v_1 calculated by "Difference Method."

Station.	δx	δt_1	v_1
Great Britain—North Germany	8° 04′	$1^{m} 41^{s}$	8.87 km/sec.
„ —Batavia	16 19	1 51	17.4 (?)
N. Germany— „	8 15	0 10	91.7 (?)

From this last table it will be seen that the Batavia time was a little too late.

89. *Group 3. South Austro-Hungary, North Italy; Nicolajew; Calcutta, Taungoo, Christchurch and Wellington; Rio de Janeiro, Ponta Delgada (Azores), Taschkent, Tiflis.* *

v_1 calculated by "Direct Method."*

Station.	x	t_1	$t_1 - t_0$	v_1
South Austro-Hungary.... Laibach. Triest. Pola.	49° 42′	$0^{h} 58^{m} 47^{s}$	$8^{m} 59^{s}$	10.24 km/sec.
North Italy...... Querce. Ximeniano. Quarto-Castello. Padova.	51 46	0 58 51	9 03	10.63
Nicolajew.	37 20	0 58 54	9 06	7.60
Calcutta.	13 42	0 52 00	2 12	11.53

(* Time observation of Rio de Janeiro was not satisfactory, while the time of commencement given by the magnetograph at Taungoo is that corresponding to the beginning of the principal portion. These two places have, therefore, been excluded from the calculation of v_1.)

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
New Zealand .... Christchurch. Wellington.	115° 24′	1 09 54	20 06	10.63
Ponta Delgada.	79 54	1 01 00	11 12	13.21
Taschkent.	11 20	0 52 24	2 36	8.07
Tiflis.	27 26	0 55 48	6 00	8.47

For large epicentral distances of over 50°, we obtain, by taking the means from the South Austro-Hungary, North Italy, and New Zealand stations, a velocity of **10.50** km per sec. The times given by the Calcutta and Ponta Delgada registers were evidently too early, while that for Nicolajew was a little too late.

The mean value of v_1 deduced from the first two sets of stations, namely, **10.45** km per sec., is the velocity of earthquake propagation partly along the Caucasus Range. This value is, however, practically identical with the transit velocity for the stations of Group 2, for which the path of propagation is situated across the flat grounds.

" Difference Method." The South Austro-Hungary and North Italy stations are near one another. Taking, therefore, the means from these, we obtain :—

$$x=50^\circ\,44'; \qquad t_1=0^{\mathrm{h}}\,58^{\mathrm{m}}\,49'$$

Combining these values with those for Calcutta, New Zealand, Ponta Delgada, Taschkent, and Tiflis, we obtain :—

Station.	δx	δt_1	v_1 " Difference Method."
		m s	km/sec.
Calcutta.	37° 02′	6 49	10.06
Christchurch. Wellington.	64 40	11 06	10.80

Station.	δx	δt_1	v_1 ("Difference Method")
		m s	km/sec.
Nicolajew.	13° 24′	– 05	(?)
Ponta Delgada.	29 10	2 12	24.73
Taschkent.	39 24	6 24	11.37
Tiflis.	23 18	3 00	14.30

Here again we see that the Calcutta time was slightly too early, while the Ponta Delgada time was probably more than 2 minutes too early. The results relating to these two stations are, therefore, to be excluded from the discussion of the velocity v_1. We have further :—

Combination of Stations.	δx	δt_1	v_1
		m s	km/sec.
New Zealand-Taschkent.	104° 04′	17 30	11.01
„ -Tiflis.	87 57	14 06	11.55
Tiflis -Taschkent.	16 06	3 24	8.77

Excepting the last combination, in which the distance (x) of each station was small, we obtain the following mean value :— v_1=**11.81** km per sec.

The exceptionally high velocity of 14.30 km per sec., obtained by combining Tiflis with Austro-Hungarian and Italian stations, can not otherwise be explained than by supposing that the transit velocity between Tiflis and the origin of disturbance was comparatively low.

90. *Group 4. Taschkent, Krakau, Strassburg; Calcutta,*

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
Taschkent.	11° 20′	0h 52m 24s	2m 36s	8.07 km/sec.
Krakau.	45 30	0 58 12	8 24	10.03
Strassburg.	53 31	0 58 26	8 38	11.48
Calcutta.	13 42	0 52 00	2 12	11.53

v_1 calculated by "Difference Method."

Combination of Stations.	δx	δt_1	v_1
Strassburg-Krakau.	8° 01′	0m 14s	63.6 (?) km/sec.
„ -Taschkent.	42 11	6 02	12.95
„ -Calcutta.	39 49	6 26	11.46
Krakau-Taschkent.	34 10	5 48	10.91
„ -Calcutta.	31 48	6 12	9.50
Calcutta-Taschkent.	2 22	(-0 24)	(?)

The two above tables show that both the Strassburg and Calcutta times were somewhat too early. Rejecting, therefore, the results relating to these two places, we obtain :—

Taschkent..........v_1 (Direct Method) = 8.07 km/sec.
Krakau.............v_1 „ =10.03 „
Krakau-Taschkent...v_1 (Difference Method)=10.91 „

91. ***Group 5. Porto Rico, Batavia, Taschkent, Upsala.***

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
Taschkent.	11° 20′	0 52 24	2 35	8.07
Batavia.	42 35	0 58 33	8 45	9.01
Jurjew.	42 49	0 57 52	8 04	9.87
Upsala.	47 41	0 58 22	8 34	10.31
Porto Rico.	118 25	1 10 25	20 37	10.64

v_1 calculated by "Difference Method."

Combination of Stations.	δx	δt_1	v_1
		m s	mk/sec.
(i) Porto Rico—Upsala.	70° 44′	12 03	10.87
(ii) „ —{Jurjew. Batavia.	75 43	11 52	11.82
(iii) „ —Taschkent.	107 05	18 01	11.01
(iv) Upsala —{Jurjew Batavia.	4 59	00 09	61.5 (?)
(v) „ —Taschkent.	36 21	5 58	11.28
(vi) {Jurjew Batavia} — „	31 22	5 49	9.99

Excluding (iv), we get the following mean values :—

$\delta x = 84°\ 31'$,........$v_1 = 11.23$ km/sec.

$\delta x = 33\ \ 52$,........$v_1 = 10.64$ „

92. ***Group 6. Japan :—Tokyo, Mizusawa ; Kobe, Osaka, Tadotsu ; Taihoku.*** The time of commemcement at Tadotsu is slightly doubtful, owing to some indistinctness in the time-marking, and is, therefore, excluded in the following calculation of v_1.

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
Tokyo, Mizusawa.	51° 33′	0 59 11	9 23	10.17
Osaka, Kobe.	48 11	0 58 39	8 51	10.08
Taihoku.	39 27	0 57 19	7 31	9.72

Taking together the 4 stations of Tokyo, Mizusawa, Osaka, and Kobe, we obtain :—v_1=**10.13** km/sec.

v_1 calculated by "Difference Method."

Combination of Stations.	δx	δt_1	v_1
		m s	km/sec.
Tokyo, Mizusawa—Osaka, Koke.	3° 22′	0 32	11.69
„ —Taihoku.	12 06	1 52	12.00
Osaka, Kobe — „	8 44	1 20	12.11

The average value of v_1 deduced from the above 3 combinations is **11.93** km per sec,

93. ***Group 7. Tiflis; Belgrade; Ischia, Messina; Querce, Ximeniano, Quarto-Castello (Florence); Rocca di papa; San Fernando; Calcutta, Taungoo*; Wellington, Christchurch (New Zealand).***

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
Tiflis.	27° 26′	0 55 48	6 00	8.47
Belgrade.	45 29	0 57 47	7 59	10.55

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
Ischia, Messina.	50° 08′	0 58 58	9 10	10.13
Querce, Ximeniano, Quarto-Castello, Rocca di papa.....	51 45	0 58 55	9 07	10.61
San Fernando.	66 47	1 02 30	12 42	9.74
Wellington, Christchurch.	115 24	1 09 54	20 06	10.63

The 7 stations of Belgrade, Ischia, Messina, Querce, Ximeniano, Quarto-Castello, and Rocca di papa, give the following means:— $x=50° 27'$; $v=10.46$ km/sec.

v_1 calculated by "Difference Method."

Combination of Stations.		δx	δt_1	v_1
			m s	km/sec.
Wellington, Christchurch	- San Fernando.	48° 37′	7 24	12.16
,,	- 6 Italian Stations.	64 11	10 58	10.84
,,	- Belgrade.	69 55	12 07	10.69
,,	- Tiflis.	87 58	14 06	11.55
San Fernando	- 6 Italian Stations.	15 34	3 34	8.09
,,	- Belgrade.	21 18	4 43	8.36
,,	- Tiflis.	39 21	6 42	10.87
6 Italian Stations	- Belgrade.	5 44	1 09	9.23
,,	- Tiflis.	23 47	3 08	14.05
Belgrade	- ,,	18 03	1 59	16.85

From the last table it will be seen that the time of commencement at San Fernando was a little too late, while that at Belgrade was a little too early. Taking together all the results, the mean value of v_1 comes out to be 11.27 km/sec.

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* Calcutta and Taungoo are excluded in the calculation of v_1. See §. 89.

94. ***Group 8. Washington, Cheltenham, Toronto, Tiflis; Kodaikanal, Batavia.***

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
		h m s	m s	km/sec.
Washington, Cheltenham.	105° 20′	1 08 32	18 44	10.41
Toronto.	101 30	1 06 36	16 48	11.18
Tiflis. (See § 89)	—	—	—	8.47
Kodaikanal. („ § 87)	—	—	—	6.70
Batavia. („ § 88)	—	—	—	9.01

Of the above 5 cases, the results relating to Toronto, Kodaikanal, and Batavia, are probably not quite accurate. (See below.)

v_1 calculated by "Difference Method."

Combination of Stations.	δx	δt_1	v_1
		m s	km/sec.
(i) Washington, Cheltenham—Toronto.	3° 50′	1 56	3.67 (?)
(ii) „ —Tiflis.	77 54	12 44	11.33
(iii) „ —Kodaikanal.	83 45	12 44	12.18
(iv) „ —Batavia.	62 45	9 59	11.64
(v) Toronto —Tiflis.	74 04	10 48	12.69
(vi) „ —Kodaikanal.	79 55	10 48	13.70
(vii) „ —Batavia.	58 55	8 03	13.55
(viii) Tiflis —Kodaikanal.	5 51	0 00	(?)
(ix) Batavia —Tiflis.	15 09	2 45	10.20
(x) „ —Kodaikanal.	21 00	2 45	14.14

Of the above 10 combinations, (i) shows that the Toronto time was a little too early. In the three cases of (v), (vi), and (vii), therefore, the velocity deduced would be a little too high.

Again, (viii) shows that the Kodaikanal time was a little too late. Consequently, the value of the velocity in the three cases of (iii), (vi), and (x), would be too high. Excluding these doubtful cases, 7 in number, we find :—

(ii) $v_1=11.33$ km per sec.
(iv) $v_1=11.64$ „
(ix) $v_1=10.20$ „

Of these three cases, the last, relating to Tiflis and Batavia, is probably not so accurate as the other two; the Batavia time being not quite exact, as remarked in § 88. The mean value of the velocity comes out to be **11.49** km per sec.

95. *Group 9. Honolulu (T.H.) and Irkutsk.*

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
Irkutsk.	28° 28′	0h 55m 44s	5m 56s	km/sec. 8.88
Honolulu.	108 27	1 04 36	14 48	13.57

v_1 calculated by "Difference Method."

Honolulu—Irkutsk :—$\delta x=79°59'$; $\delta t_1=8^m\ 52^s$. $v_1=16.70$ km/sec.

Judging from the above values of the velocity v_1, the Honolulu time seems to have been a little too early.

96. *Group 10. Formosa, Bairût (Asia Minor).*

v_1 calculated by "Direct Method."

Station.	x	t_1	t_1-t_0	v_1
Taihoku.	39° 27′	0h 57m 19s	7m 31s	km/sec. 9.72
Bairût.	34 41	0 58 00	8 12	7.83

v_1 calculated by "Difference Method."

Bairût—Taihoku.....$\delta x=4°46'$; $\delta t_1=-41$ sec.; $v_1=(?)$km/sec.

The time of commencement at Bairût was evidently a little too late.

97. *Single Stations.* "Direct Method."

Station.	Epicentral Distance.		t_1-t_0		v_1
Mauritius.	55°	15′	9m	06s	11.24 km/sec.
Cape Town.	85	46	12	42	12.51
Baltimore.	104	47	20	42	9.37

SUMMARY.

98. *Velocity and Nature of Path.* According to the velocity calculations by "difference method" given above, the time (t_1) of earthquake occurrence at some of the stations seem to have been slightly inaccurate, as follows:—

(*a*) t_1 registered at Kodaikanal, Batavia, San Fernando, Baltimore and Bairût was too late; (*b*) t_1 registered at Calcutta, Ponta Delgada, Belgrade, Strassburg, Toronto, and Honolulu, was too early. Some of these stations, whose time observation leads to the values of the transit velocity much different from those for the others, have been excluded in the deduction of the average group velocity.

v_1 calculated by "direct method." Comparing together the results for the different groups of stations, we see that there was apparently no general *marked* dependence of v_1 on the nature of the path of the seismic waves; the most trustworthy values of the mean velocity being as follows:—

Group.	Stations.	Nature of Wave Path.	Mean x.	Mean v_1
				km/sec.
1	Tacubaya, Toronto, Victoria, B.C.	Through North Pole.	114° 12′	10.97
2	N. Germany, Great Britain.	Across plane regions.	54 45	10.36
3	S. Austro-Hungary and N. Italy.	Along mountain ranges.	50 44	10.44
,,	New Zealand.		115 24	10.63
5	Jurjew, Upsala.		45 15	10.09
6	Japan.	Through Tibet and China.	49 52	10.13
7	Central and S. Italy.		51 13	10.45
8	Washington, Cheltenham.		105 20	10.41

The stations of Group 1 and New Zealand give high velocities of 10.97 to 10.63 km per sec., the epicentral distances being great and equal to about 115°. It is, however, remarkable that the velocities for Group 2 (mean $x=54^\circ\ 45'$) and Group 3 (mean $x=50^\circ\ 44'$) were practically identical, namely, 10.36 and 10.44 km per sec., although the nature of the regions, through which the seismic waves were propagated, differed widely in the two cases, being respectively across plane grounds and along mountain ranges. The path of the waves for Group 1 stations, which approximately passed through the North Pole, is laid for the greater part across flat grounds.

The 4 Japanese stations of Tokyo, Mizusawa, Osaka, and Kobe (Group 6) give a velocity of 10.13 km per sec., which is about 0.27 km less than those of Group 2 and Group 3 stations. This difference *may* be due to the fact that the seismic waves passed, before reaching Japan, through China and the plateau of Tibet; a natural supposition in this connection being that the propagation velocity would be greater in suboceanic or depressed regions, than in plateau or elevated grounds, on account of the difference of rigidity and elasticity of the material composing the different portions of the earth's surface.

Taking the average from the different groups of stations given in the preceding table, we find :—

for $x=45°$ to $115°$;.... $v_1=\mathbf{10.44}$ km per sec.

99. v_1 *calculated by "Difference Method."*

The following table gives the mean values of the transit velocity v_1 for the different groups of stations.

Group.	Stations.	Limits of x.	Mean v_1
1	Tacubaya, Toronto, Victoria, B.C., Colaba.	13° 28′ — 128° 47′	km/sec. 11.63
2	Great Britain, North Germany.	50 36 — 58 54	10.34
3	S. Austro-Hungary, N. Italy, Calcutta, Christchurch, Wellington, Taschkent, Tiflis.	13 42 — 115 24	11.81
5	Porto Rico, Upsala, Jurjew, Batavia, Taschkent	11 20 — 118 25	11.23
6	Japan:—Tokyo, Mizusawa, Osaka, Kobe, Taihoku.	39 27 — 51 33	11.93
7	Tiflis, Belgrade, 6 Italian Stations, San Fernando, New Zealand.	27 26 — 115 24	11.27
8	Washington, Cheltenham, Tiflis, Batavia.	27 26 — 105 20	11.49

Taking the average from the seven groups of stations contained in the above table, with the exception of the 2nd, in which the distance difference was too small, we obtain :—

for $x=11° 20'$ to $128° 47'$; mean $v_1=\mathbf{11.56}$ km per sec.

100. ***Velocity v_1 calculated by "Direct Method," without reference to the Paths of the Seismic Waves.*** In the following table, the different stations are arranged simply according to the epicentral distance and conveniently divided into a number of groups, the velocity v_1 having been calculated by "direct method." Those stations marked with *asterisks* have not been taken in the deduction of the mean values of the velocity,[*]

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[*] See page 148.

TABLE IX. v_1 calculated by "Direct Method."

Station.	Epicentral Distance $=x$.	Time of occurrence of 1st Prel. Tremor $=t_1$	v_1
		h m s	km/sec.
Earthquake Origin.	—	**0 49 48**	—
Dehra Dun.	1° 45′	0 50 38	—
Taschkent.	11 20	0 52 24	8.07
Colaba.	13 28	0 53 08	7.48
Calcutta.*	13 42	0 52 00	11.53
Mean.	**12 24**	**0 52 46**	**7.78**
Kodaikanal *	21 35	0 55 48	6.66
5 Caucasus Stations.‡	27 11	0 55 39	8.60
Tiflis.	27 26	0 55 48	8.47
Irkutsk.	28 28	0 55 44	8.88
Mean.	**27 57**	**0 55 46**	**8.68**
Nikolajew.*	37 20	0 58 54	7.60
Taihoku.	39 27	0 57 19	9.72
Bairût.*	34 41	0 58 00	7.83
Batavia.*	42 35	0 58 33	9.01
Jurjew.	42 49	0 57 52	9.87
Manila.	43 34	0 58 25	9.36
Belgrade.	45 29	0 57 47	10.55
Krakau.	45 30	0 58 12	10.03
Mean.	**43 22**	**0 57 55**	**9.91**
Tadotsu.	47 02	0 58 49	9.66
Upsala.	47 41	0 58 22	10.31
Kobe.	48 03	0 58 26	10.30
Osaka.	48 19	0 58 51	9.89

* Not taken in deducing the means.

‡ Achalkalaki, Derbent, Schemacha, Borshom, Batum.

Station.	Epicentral Distance $=x$.	Time of occurrence of 1st Prel. Tremor $=t_1$	v_1
		h m s	km/sec.
Laibach.	48° 19′	0 58 46	9.98
Messina.	49 46	0 59 00	10.02
Potsdam.	49 48	0 58 46	10.28
Triest.	49 52	5 58 44	10.34
Pola.	49 55	5 58 50	10.23
Leipzig.	50 16	0 58 44	10.42
Ischia.	50 30	0 58 56	10.24
Jena.	50 48	0 58 54	10.20
Rocca di papa.	51 15	0 58 51	10.49
Padua.	51 20	0 58 58	10.34
Tokyo.	51 26	0 59 08	10.20
Hamburg.	51 34	0 58 14	11.32
Mizusawa.	51 39	0 59 08	10.25
Göttingen.	51 45	0 58 55	10.51
Querce.	51 54	0 59 08	10.30
Ximeniano.	51 55	0 58 33	10.99
Quarto-Castello.	51 56	0 58 49	10.67
Strassburg.	53 31	0 58 26	11.48
Mean.	**50 24**	**0 58 48**	**10.38**
Kew.	58 05	1 00 12	10.33
Edinburgh.	58 48	1 00 00	10.67
Birmingham.	58 49	1 00 35	10.10
Shide.	58 52	1 01 00	9.73
Liverpool.	59 18	1 00 36	10.17
Paisley.	59 30	1 00 00	10.80
Mean.	**58 54**	**1 00 24**	**10.30**
San Fernando.	66 47	1 02 30	9.74

Station.	Epicentral Distance $= x$	Time of occurrence of 1st Prel. Tremor $= t_1$	v_1
		h m s	km/sec.
Ponta Delgada.*	79° 54′	1 01 00	13.21
Cape Town.	85 46	1 02 30	12.51
Mean.	**73 07**	**1 02 30**	**10.66**
Victoria, B.C.	97 42	1 06 48	10.69
Toronto.	101 30	1 06 36	11.19
Baltimore.*	104 47	1 10 30	9.37
Washington, D.C.	105 17	1 08 25	10.47
Cheltenham.	105 22	1 08 39	10.35
Honolulu.*	108 27	1 04 36	13.57
Mean.	**103 03**	**1 07 49**	**10.61**
Christchurch.	115 03	1 10 00	10.54
Wellington.	115 45	1 09 48	10.72
Porto Rico.	118 25	1 10 25	10.64
Tacubaya.	128 39	1 11 25	10.03
Mean.	**121 16**	**1 10 37**	**10.79**

The mean values of the velocity v_1 contained in the above table are as follows.

TABLE X. Mean Values of v_1 calculated by "Direct Method."

Station.	Epicentral Distance $= x$.	v_1
		km/sec.
Taschkent, Colaba	12° 24′	7.78
Tiflis, Irkutsk.	27 57	8.68
Taihoku, Jurjew, Manila, Belgrade, Krakau.	43 22	9.91
Upsala. Osaka, Kobe, Laibach, Triest, Pola, Messina, Ischia, Jena, Tokyo,		

Stations.	Epicentral Distance $=x$.	v_1
		km. sec.
Hamburg, Mizusawa, Rocca di papa, Padova, Querce, Ximeniano, Quarto-Castello, Leipzig, Potsdam, Göttingen, Strassburg.	50° 24′	10.38
Kew, Birmingham, Liverpool, Paisley, Edinburgh, Shide	58 54	10.30
San Fernando and Cape Town.	73 07	10.66
Toronto, Victoria, B.C., Washington, Cheltenham.	103 03	10.61
Christchurch, Wellington, Porto Rico, Tacubaya.	121 16	10.79

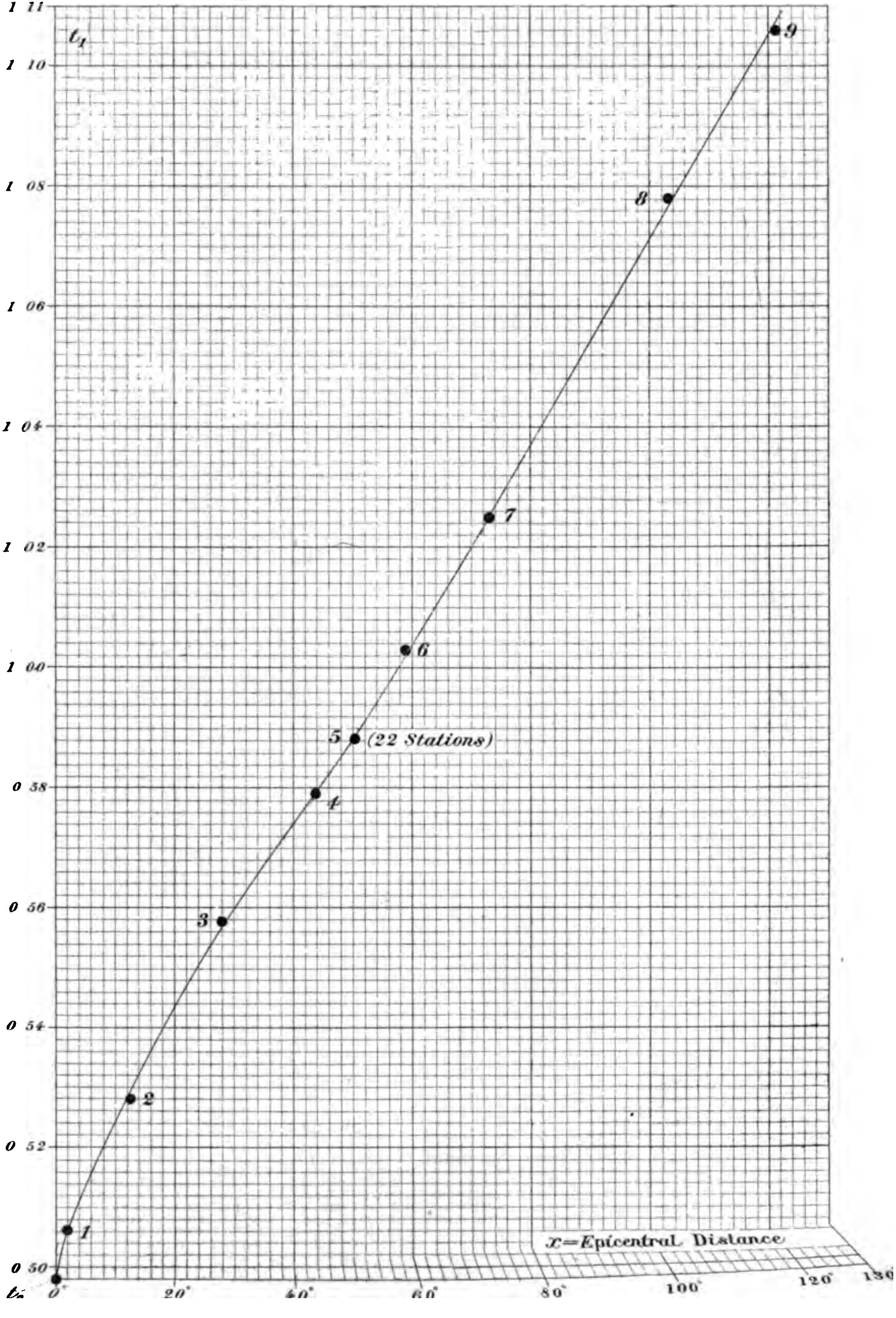
As is graphically shown in Fig. 9, the velocity v_1 calculated by "direct method" increased, between the earthquake origin and the epicentral distance of x=about 50°, linearly up to a value of 10.38 km per sec., the velocity at the immediate vicinity of the epicentre being probably some 7 km per sec. For the x greater than 50°, the velocity remained very nearly constant, the maximum being 10.79 km per sec., for $x=121°16'$. According to the above table, the mean velocity (v_1) is as follows:—

$v_1=$**10.52** km per sec. (for $x=50°$ to 121°; mean $x=76.°$)

For the sake of comparison, I give in Fig. 9, also the relation between the epicentral distance and the velocity v_1 calculated by "direct method" for the San Francisco earthquake of April 18, 1906.

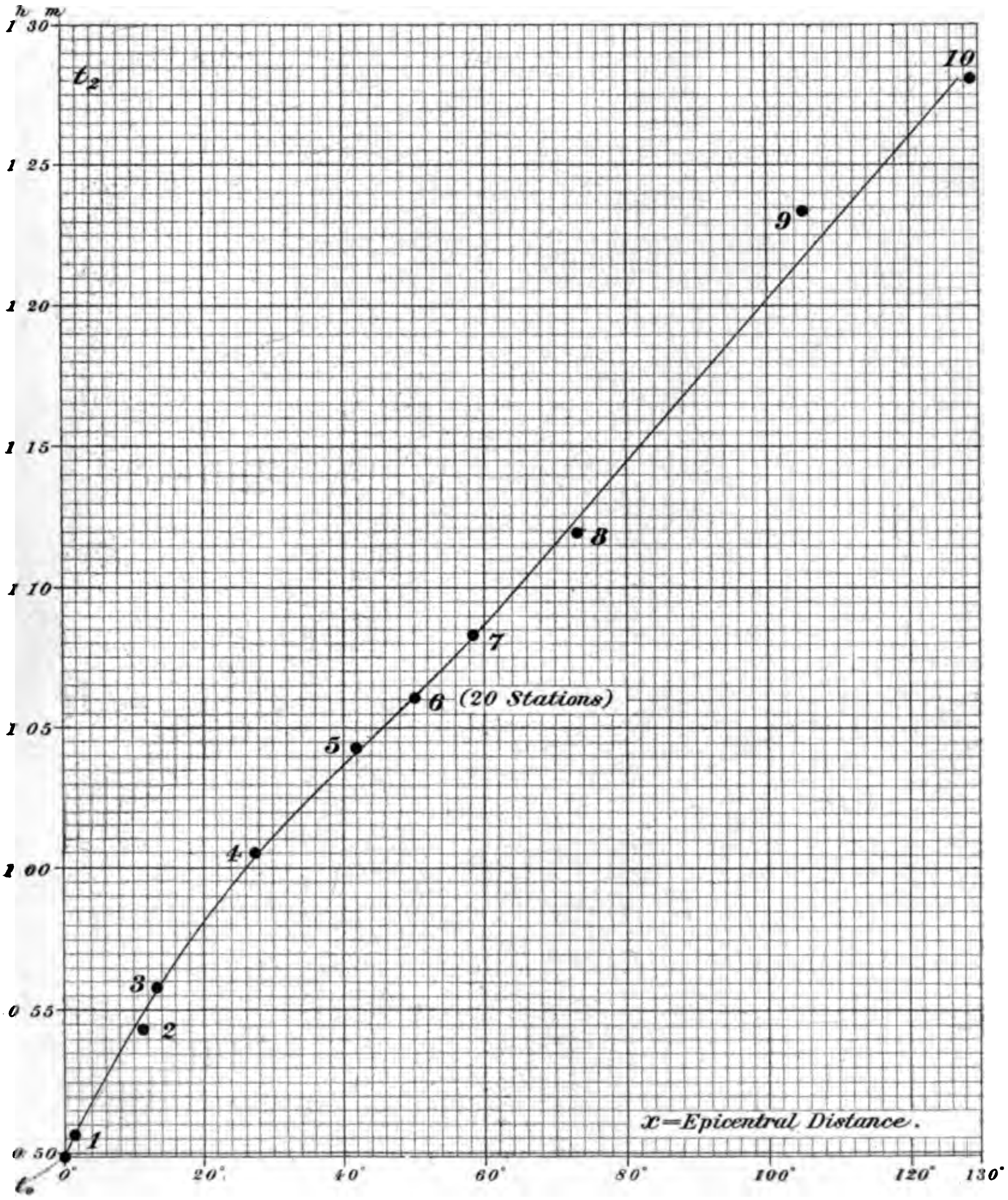
101. ***Mean Value of the Velocity v_1 calculated by "Diffence Method."*** The relation between the mean group values of the epicentral distance and the time of occurrence, given in Table IX, is graphically shown in Fig. 7, from which it will be seen

Fig. 7. Indian Earthquake of April 4, 1905. Relation of the Time of Earthquake Occurrence to the Epicentral Distance.



Pl. IV.

Fig. 8. Indian Eqke of 1905. Relation to the Epicentral Distance of the Time of Occurrence of the 2nd Preliminary Tremor.



Pl. V.

Indian Eqke of 1905. Relation to the Epicentral Distance of the Velocities of the 1st and 2nd Preliminary Tremors, Calculated by "Direct Method."

Fig. 9.

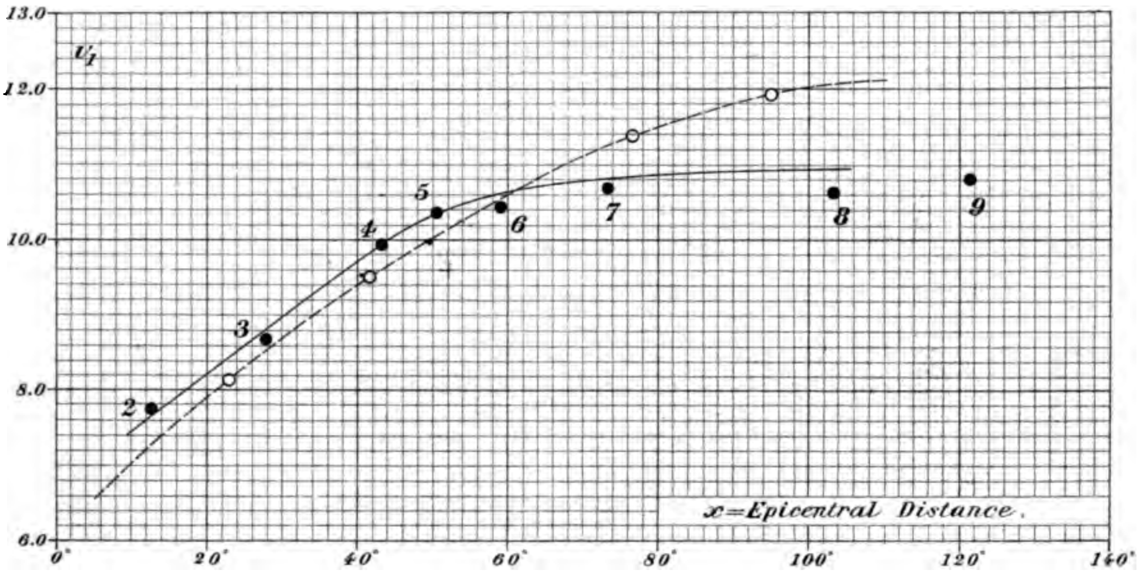
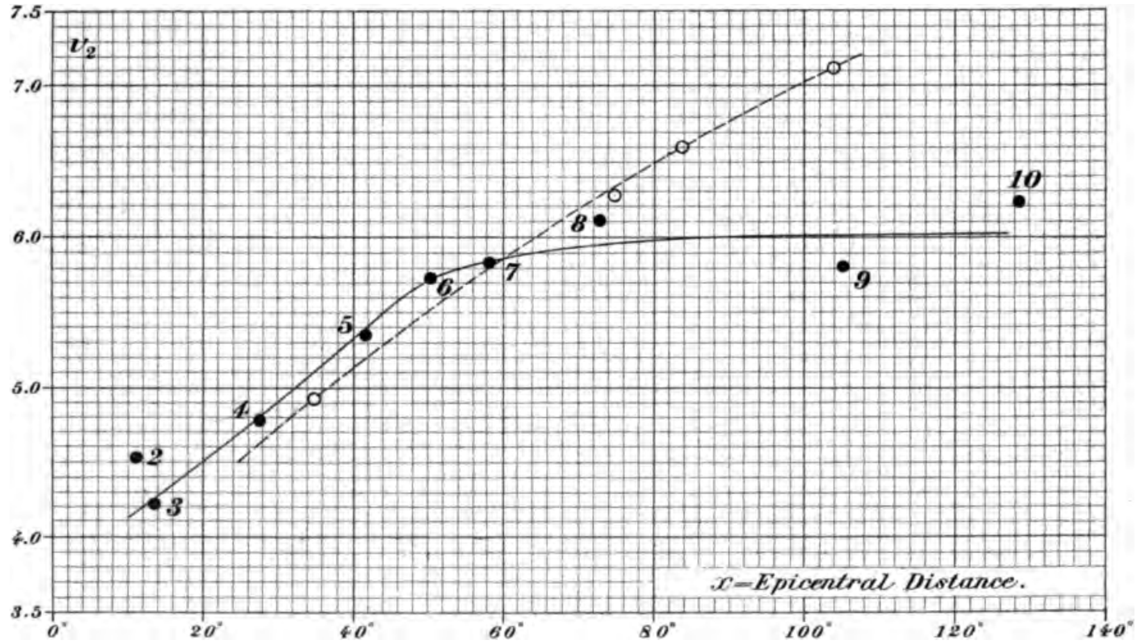


Fig. 10.



Black dots (●) and full line relate to Kangra Eqke.

Small white circle (○) and dotted line relate to San Francisco Eqke.

that the time (t_1) increased almost linearly with the distance (x) between about 30° and 120° (maximum limit).

Taking from Table IX, the mean group values of the epicentral distance and the corresponding time of occurrence of the 1st preliminary tremor, and calculating by the method of Least Squares, we find for the limits of x between 27° 57′ and 121° 16′,

$$v_1 = \mathbf{11.36} \text{ km per sec.}$$

Chapter V. Velocity of Propagation of the 2nd Preliminary Tremor.

102. ***Time of Commencement (t_2) and Transit Velocity (v_2) at Different Stations.*** The following table gives the epicentral distance (x) and the time of commencement (t_2) of the 2nd preliminary tremor for the 42 stations, whose seismograms indicated the last mentioned phase of motion with clearness; the different stations being divided, according to the epicentral distance, into a number of groups. The velocity v_2 given in the 4th column of the table has been calculated by " direct method " according to the formula

$$v_2 = \frac{x}{t_2 - t_0};$$

t_0 being the time of earthquake occurrence at the origin, assumed to be $0^h\ 49^m\ 48^s$ (G.M.T.).

Again, as will be seen from the results of the calculation of the velocity v_2 by " difference method " the times t_2 for Kodaikanal, Taungoo, and Batavia, seem to be a little too late. Accordingly these 3 stations (marked with *asterisks* in the Table) have been excluded in deducing the mean values of the velocity v_2; the weight of the observations at those places, where the seismograms were apparently not quite satisfactory, being taken to be half that of the observations at the remaining places.

Table XI. Time of Commencement and Transit Velocity of the 2nd Preliminary Tremor.

Station.	Epicentral Distance $= x$.		Time of commencement of 2nd P. T. $= t_2$.			v_2 Calculated by "Direct Method."
			h	m	s	Km/sec.
Eqke Origin.	—		**0**	**49**	**48**	—
Dehra Dun.	1°	45′	0	50	38	—
Taschkent.	11	20	0	54	26	4.52
Colaba (Bombay).	13	28	0	56	39	3.64
Barrackpur.	13	32	0	55	41	4.26
Calcutta.	13	42	0	55	09	4.74
Mean.	**13**	**34**	**0**	**55**	**50**	**4.21**
Kodaikanal.*	21°	35′	0	59	43	4.03
Taungoo.*	21	44	1	00	03	3.93
Tiflis.	27	26	1	00	31	4.74
5 Caucasus Stations.	27	11	1	00	22	4.76
Irkutsk.	28	28	1	00	52	4.77
Mean.	**27**	**42**	**1**	**00**	**35**	**4.76**
Taihoku.	39	27	1	03	25	5.36
Batavia.*	42	35	1	05	33	5.01
Jurjew.	42	49	1	04	29	5.40
Manila.	43	34	1	05	03	5.29
Mean.	**41**	**57**	**1**	**04**	**19**	**5.35**

TABLE XI. *Cont.*

Station.	Epicentral Distance $=x$.		Time of commencement of 2nd P. T. $=t_2$.			v_2 Calculated by "Direct Method."
			h	m	s	Km/sec.
Tadotsu.	47°	02′	1	05	49	5.44
Upsala.	47	41	1	05	19	5.69
Kobe.	48	03	1	05	26	5.69
Osaka.	48	19	1	06	03	5.51
Laibach.	49	19	1	06	08	5.59
Messina.	49	46	1	06	15	5.60
Potsdam.	49	48	1	05	51	5.75
Triest.	49	52	1	05	43	5.80
Pola.	49	55	1	05	58	5.72
Leipzig.	50	16	1	05	53	5.79
Ischia.	50	30	1	06	14	5.69
Jena.	50	48	1	06	06	5.78
Rocca di papa.	51	15	1	06	09	5.80
Padova.	51	20	1	06	42	5.63
Tokyo.	51	26	1	06	25	5.73
Mizusawa.	51	39	1	06	28	5.74
Göttingen.	51	45	1	06	12	5.84
Querce.	51	54	1	06	24	5.79
Ximeniano.	51	55	1	05	47	6.01
Quarto-Castello.	51	56	1	06	02	5.92
Mean.	**50**	**12**	**1**	**06**	**03**	**5.73**
Mauritius.	55	15	1	07	03	5.93
Birmingham.	58	49	1	08	56	5.69
Paisley.	59	30	1	08	18	5.96
Mean.	**58**	**06**	**1**	**08**	**18**	**5.82**

TABLE XI. *Cont.*

Station.	Epicentral Distance=x.		Time of commencement of 2nd P. T.=t_2.			v_2 Calculated by "Direct Method."
			h	m	s	km/sec.
San Fernando.	66°	54′	1	11	42	5.66
Cape Town.	85	46	1	12	27	7.01 (?)
Mean.	**73**	**11**	**1**	**11**	**57**	**6.11**
Cheltenham.	105	22	1	23	22	5.81
Washington.	105	17	1	23	27	5.79
Mean.	**105**	**20**	**1**	**23**	**25**	**5.80**
Wellington.	115	45	1	29	54	5.34
Tacubaya.	128	47	1	28	03	6.23

The relation to the epicentral distance (x) of the time (t_2) of occurrence of the 2nd preliminary tremor is illustrated in Fig. 8, from which it will be seen that up to x=about 50° the rate of increase of the time relative to the distance was a little smaller than that of simple proportion, the maximum time deviation being about 1 min. Between x=50° and x=130°, the relation seems to become more nearly one of proportion.

According to Table XI, the mean values of v_2 are as follows:—

			km/sec.	
(i)	x=11°	20′ ;	v_2=4.52	(Taschkent).
(ii)	13	34	4.21	(3 Indian Stations).
(iii)	27	42	4.76	(Tiflis and 5 Caucasian Stations).
(iv)	41	57	5.35	(Taihoku and Manila).
(v)	50	12	5.73	(20 Stations in Japan and Central Europe).
(vi)	58	06	5.82	(Mauritius and 2 British Stations).
(vii)	73	11	6.11	(San Fernando and Cape Town).
(viii)	105	20	5.80	(Cheltenham and Washington).
(ix)	128	47	6.23	(Tacubaya).

Of the above 9 groups, the x and v_2 for (v) have been obtained by taking the means from 20 stations in Japan, Italy, Austria-Hungary, Germany, and Sweden. As is graphically represented in Fig. 10, the velocity v_2 steadily increased with the epicentral distance, till it reached a value of 5.68 km per sec. for $x=50°16'$ (Group v), the mean rate of the velocity increase being about 0.038 km per degree of the distance. For the distances over about 60°, the rate of increase of the velocity seems to become smaller. The average value of the velocity, between $x=41°57'$ and $x=128°47'$, comes out to be **5.82** km per sec.

For the sake of comparison, the case of the San Francisco earthquake of April 18, 1906, is also illustrated in Fig. 10.*

To find out the dependence, if any, of v_2 on the nature of the path of seismic propagation, I give in the succeeding §§, the results of the velocity calculation, according to the "direct" and "difference" methods, for the different groups of stations (§ 85).

103. *Group 1. Tacubaya, Colaba (Bombay), Kodaikanal (Madras).*

"Direct Method."

Station.	x	t_2-t_0	v_2
Tacubaya.	128° 47′	38m 15s	6.23 km/sec.
Colaba.	13 28	6 51	3.64
Kodaikanal.	21 35	9 55	4.03

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* The *Bulletin of the Imperial Earthquake Investigation Committee*, Vol. I, No. I, p. 37.

"Difference Method."

Combination of Stations.	δx	δt_2	v_2
			km/sec.
Tacubaya -Colaba.	115° 19′	$31^m 24^s$	6.80
„ -Kodaikanal.	107 12	28 20	7.01
Kodaikanal-Colaba.	8 07	3 04	7.27

104. *Group 2. Great Britain, North Germany, Batavia.*

"Direct Method."

Place.	x	t_2-t_0	v_2
		m s	km/sec.
Great Britain Birmingham	58° 49′	19 08	
Paisley.	59 30	18 30	
Mean.	59 10	18 49	5.82
North Germany Potsdam.	49 48	16 03	
Leipzig.	50 16	16 05	
Jena.	50 48	16 18	
Göttingen.	51 45	16 24	
Mean.	50 39	16 13	5.79
Batavia.	42 35	15 45	5.01

"Difference Method."

Combination.	δx	δt_2	v_2
		m s	
Great Britain-North Germany.	8° 31′	2 36	6.07 km per sec.
„ -Batavia.	16 35	3 04	10.01
North Germany-Batavia.	8 04	0 28	(?)

105. *Group 3. South Austro-Hungary, North Italy, Calcutta, Taungoo, New Zealand, Tiflis, Taschkent.*

"Direct Method."

Station.		x		t_2-t_0		v_2
South Austro-Hungary.	Laibach.	49°	19′	16^m	20^s	km/sec.
	Triest.	49	52	15	55	
	Pola.	49	55	16	10	
Mean		**49**	**42**	**16**	**08**	**5.70**
North Italy	Padova.	51	15	16	21	
	Rocca di papa.	51	20	16	54	
	Querce.	51	54	16	36	
	Ximeniano.	51	55	15	59	
	Quarto Castello.	51	56	16	14	
Mean		**51**	**40**	**16**	**25**	**5.83**
Calcutta.		13	42	5	21	4.74
Taungoo.		21	44	10	15	3.93*
Wellington.		115	45	40	06	5.34
Tiflis.		27	26	10	43	4.74
Taschkent.		11	20	4	38	4.52

"Difference Method."

Combination of Stations.	δx		δt_2		v_2
S. Austro-Hungary-Taungoo.	27°	58′	5^m	53^s	km/sec. 8.80
„ -Tiflis.	22	16	5	25	7.61
„ -Taschkent.	38	22	11	30	6.18
„ -Calcutta.	36	00	10	47	6.18

Combination of Stations.	δx	δt_2	v_2
Wellington-S.Austro-Hungary.	66° 03′	$23^m\ 58^s$	5.10 km/sec.
„ -Calcutta.	102 03	34 45	5.44
„ -Taungoo.	94 01	29 51	5.83
„ -North Italy.	64 05	23 41	5.01
„ -Tiflis.	88 19	29 23	5.56
„ -Taschkent.	104 25	35 28	4.61
North Italy-S.Austro-Hungary.	1 58	00 17	(?)
„ -Calcutta.	37 58	11 04	6.36
„ -Taungoo.	29 56	6 10	9.00
„ -Tiflis.	24 14	5 42	7.88
„ -Taschkent.	40 20	11 47	6.34
Tiflis -Calcutta.	13 44	5 22	4.74
„ -Taungoo.	5 42	0 28	(?)
„ -Taschkent.	16 06	6 05	5.86
Taungoo -Calcutta.	8 02	4 54	3.03
„ -Taschkent.	10 24	5 37	3.43

106. ***Group 5. Taschkent, Jurjew (Dorpat), Upsala, Batavia.****

"Direct Method."

Station.	x	t_2-t_0	v_2
Taschkent	11° 20′	$4^m\ 38^s$	4.52 km/sec.
Jurjew (Dorpat)	42 49	14 41	5.40
Upsala.	47 41	15 31	5.69

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* Batavia excepted. (See § 104).

"Difference Method."

Combination of Stations.	δx	δt_2	v_2
Upsala—Jurjew.	4° 52′	0^{m} 50^{s}	10.82(?)km/sec
„ —Taschkent.	36 21	10 53	6.19
Jurjew — „	31 29	10 03	5.81

107. ***Group 6. Japan, Taihoku, Tadotsu, Kobe, Osaka, Tokyo, Mizusawa.***

"Direct Method."

Place.	x	$t_2 - t_0$	v_2
Taihoku.	39° 27′	13^{m} 37^{s}	5.36 km/sec.
Tadotsu.	47 02	16 01	5.44
Kobe.	48 03	15 38	5.69
Osaka.	48 19	16 15	5.51
Tokyo.	51 26	16 37	5.73
Mizusawa.	51 39	16 40	5.74

"Difference Method."

Combination of Stations.	δx	δt_2	v_2
Tokyo. Mizusawa. } — { Tadotsu. Kobe. Osaka.	3° 45′	0^{m} 40^{s}	10.40 km/sec.
„ — Taihoku.	12 06	3 01	7.43
Tadotsu. Kobe. Osaka. } — „	8 21	2 21	6.57

108. ***Group 7. Tiflis; Ischia, Messina; Ximeniano, Querce, Quarto-Castello, Rocca di papa; San Fernando; Calcutta; Wellington.***

" Direct Method "

Stations.	x	t_2-t_0	v_2
Tiflis.	27° 26′	$10^{m}\ 43^{s}$	km/sec. 4.74
Ischia, Messina.	50 08	16 27	5.65
Ximeniano, Querce, Quarto-Castello, Rocca di papa.	51 45	16 17	5.88
San Fernando.	66 54	21 54	5.66
Calcutta.	13 42	5 21	4.74
Wellington.	115 45	40 06	5.35

" Difference Method."

Combination of Stations.		δx.	δt_2	v_2
Wellington	- Tiflis.	88° 19′	$29^{m}\ 23^{s}$	km/sec. 5.57
"	- Ischia, Messina.	65 37	23 39	5.14
"	- San Fernando.	48 51	18 12	4.97
"	- Ximeniano, Querce, Quarto-Castello, Rocca di papa.	64 00	23 49	4.98
"	- Calcutta.	102 03	34 45	5.44
San Fernando	- Tiflis.	39 28	11 11	6.53
"	- Ischia, Messina.	16 46	5 27	5.70
"	- Ximeniano, Querce, Quarto-Castello, Rocca di papa.	15 09	5 37	5.00
"	- Calcutta.	53 12	16 33	5.59
Ischia, Messina	- Tiflis.	22 42	5 44	7.34
"	- Calcutta.	36 26	11 06	6.08

Combination of Stations.		δx	δt_2	v_2
Ximeniano, Querce, Quarto-Castello, Rocca di papa.	-Tiflis.	24° 19′	$5^m 34^s$	8.10 km/sec.
„	-Calcutta.	38 03	10 56	6.45
Tiflis	- „	13 44	5 22	4.74

109. ***Group 8. Washington, Cheltenham, Tiflis, Kodaikanal, Batavia.***

"Direct Method."

Place.	x	t_2-t_0	v_2
Washington.	105° 17′	$33^m 39^s$	5.79 km/sec.
Cheltenham.	105 22	33 34	5.81
Tiflis.	27 26	10 43	4.74
Kodaikanal.	21 35	9 55	4.03
Batavia.	42 35	15 45	5.01

"Difference Method."

Combination of Stations.		δx.	δt_2	v_2
Washington Cheltenham	-Tiflis.	77° 54′	$22^m 54^s$	6.30 km/sec.
„	-Kodaikanal.	83 45	23 42	6.54
„	-Batavia.	62 45	17 52	6.50
Tiflis	-Kodaikanal.	5 51	0 48	13.52 (?)
Batavia	-Tiflis.	15 09	5 02	5.57
„	-Kodaikanal.	21 00	5 50	6.67

110. *Single Stations:— Manila, Mauritius, Cape Town.*

"Direct Method."

Place.	x	t_2-t_0	v_2
Manila.	43° 34′	15^m 15^s	5.29 km/sec.
Mauritius.	55 15	17 15	5.93
Cape Town.	85 46	22 39	7.01
Irkutsk.	28 28	11 04	4.77

SUMMARY.

111. ***v_2 for the different Groups, calculated by "Direct Method."*** The values of the velocity V_2 for the different stations, calculated by "direct method," are collected in Table XII.

TEBLE XII. v_2 calculated by "Direct Method."

Place.	Epicental Distance.	v_2
	Group 1.	
Colaba.	13° 28′	3.64 km/sec.
Kodaikanal.	21 35	4.03
Takubaya.	128 47	6.23
	Group 2.	
Batavia.	42° 35′	5.01
North Germany.	50 36	5.79
Great Britain.	59 10	5.82
	Group 3.	
Taschkent.	11° 20′	4.52
Calcutta.	13 42	4.74
Tiflis.	27 26	4.74
South Austro-Hungary.	49 42	5.70
North Italy.	51 40	5.83
Wellington.	115 45	5.34

Place.	Epicentral Distance	v_2
	Group 5.	
Taschkent.	11° 20′	4.52 km/sce.
Jurjew (Dorpat)	42 49	5.40
Upsala.	47 41	5.69
	Group 6.	
Taihoku.	39° 27′	5.36
Tadotsu.	47 02	5.44
Kobe.	48 03	5.69
Osaka.	48 19	5.51
Tokyo.	51 26	5.73
Mizusawa.	51 39	5.74
	Group 7.	
Calcutta.	13° 42′	4.74
Tiflis.	27 26	4.74
Ischia, Messina	50 08	5.65
Ximeniano, Querce, Quarto-Castello, Rocca di papa.	51 45	5.88
San Fernando.	66 54	5.66
Wellington.	115 45	5.35
	Group 8.	
Kodaikanal.	21° 35′	4.03
Tiflis.	27 26	4.74
Batavia.	42 35	5.01
Washington.	105 17	5.79
Cheltenham.	105 22	5.81
	Single Stations.	
Irkutsk.	28° 28′	4.77
Manila.	43 34	5.29
Mauritius.	55 15	5.93
Cape Town.	85 46	7.01

Taking for the different groups the mean values of v_2, for the x above about 40°, we find :—

Group (1).... Mean $x=128°\ 47'$; $v_2=6.23$ km/sec. (Tacubaya only).
„ (2) „ $x=52\ 25$; $v_2=5.65$ „
„ (3) „ $x=63\ 42$; $v_2=5.68$ „
„ (5) „ $x=45\ 15$; $v_2=5.55$ „
„ (6) „ $x=48\ 12$; $v_2=5.60$ „
„ (7) „ $x=67\ 15$; $v_2=5.68$ „
„ (8) „ $x=92\ 47$; $v_2=5.64$ „

Thus the Group I (Tacubaya) observation gives a velocity of 6.23 km/sec. for the distance of $x=128°\ 47'$. For all the other groups, whose mean distance x was from 45° 15′ to 92° 47′, the velocity v_2 remained very nearly constant, varying only between 5.55 and 5.68 km/sec. Taking the average of the values of the velocity for the groups (2) to (8), we obtain, for $x=40°$ to 115° 45′ :—

Mean $x=61°\ 36'$, $v_2=$ **5.63** km/sec. (direct method).

Again, taking only the observations relating to Great Britain, North Germany, North Italy, South Austria-Hungary, and Tokyo, and Mizusawa, we obtain :—

(i) Great Britain, North Germany. $x=54°\ 53'$; $v_2=5.81$ km/sec.
(ii) North Italy, South Austria-Hungary. $x=50°\ 41'$; $v_2=5.77$ „
(iii) Tokyo, Mizusawa, (Japan). $x=51°\ 33'$; $v_2=5.74$ „

Thus again, for these sets of stations, for which the distance was nearly alike ($x=50°\ 41'$ to 54° 53′), the velocity v_2 varied only between 5.74 km/sec. for Japan to 5.81 km/sec. for Great Britain and North Germany. If, however, these slight differences in the value of v_2 denote anything, we may conclude from the above three sets, (i), (ii), and (iii), and the Group I, as follows :—The propagation velocity v_2 was greatest along the suboceanic path, through the North Pole, and was slightly greater along the flat region path to Great Britain and North Germany than along the mountainous path to North Italy and South Austria-Hungary, being least along the path to Japan across the plateau of Tibet.

112. ***Average Value of v_2 calculated by "Difference Method."*** Taking from Table XI, the mean values of the time (t_2) of commencement of the 2nd preliminary tremor corresponding to different epicentral distances over 27° 42′ (§ 102), and calculating by the Method of Least Squares, we obtain, for $x=27^\circ 42'$ to $128^\circ 47'$:—

$$v_2 = \mathbf{6.46} \text{ km/sec};$$

this having no particular reference to the paths of the seismic propagation.

Chapter VI. Velocities of Propagation of the Principal Portion.

113. In this Chapter I will consider the transit velocities of the vibrations at the commencement of the 3rd and 5th sections, or the 1st and 3rd phases of the principal portion, and that of the absolute maximum indicated in the Milne horizontal pendulum seismograms.

114. ***Transit Velocity (v_3) of the 1st Phase of Principal Portion.*** Table XIII gives for the 12 stations of Taihoku, Tadotsu, Osaka, Tokyo, Leipzig, Göttingen, Rocca di papa, Quarto-Castello, Birmingham, Cheltenham, Washington, and Tacubaya, the epicentral distance (x), the time (t_3) of commencement of the principal portion, the time interval (t_3-t_0), and the velocity (v_3) calculated by "direct method." For the remaining stations it was difficult to fix clearly the end of the 2nd preliminary tremor.

TABLE XIII. Observation of the 1st Phase of Principal Portion; v_3 calculated by "Direct Method."

Station.	Epicentral Distance $=x$.	Time of comm't. of the Princ. Portion $=t_3$	t_3-t_0	v_3 cal. by "Direct Method."
EQ. Origin.	....	**$0^h49^m48^s$**	—	—
(i) Taihoku.	39° 27′	1 08 50	$19^m\ 02^s$	3.83 km/sec.
(ii) Tadotsu.	47 02	1 13 31	23 43	3.68
(ii) Osaka.	48 19	1 12 58	23 10	3.87
(ii) Leipzig.	50 16	1 13 35	23 47	3.92
(ii) Rocca di papa.	51 15	1 13 02	23 14	3.81
(ii) Tokyo.	51 26	1 14 07	24 19	3.90
(ii) Göttingen.	51 45	1 13 43	23 55	4.01
(ii) Quarto-Castello.	51 56	1 13 35	23 47	4.05
Mean.	**50 17**	**1 13 30**	**23 42**	**3.92**
(iii) Birmingham.	58 49	1 16 33	26 45	4.07
(iv) Chaltenham.	105 22	1 35 33	45 45	4.27
(iv) Washington.	105 17	1 35 36	45 48	4.26
Mean.	**105 20**	**1 35 35**	**45 47**	**4.27**
(v) Tacubaya.	128 47	1 43 45	53 57	4.42

As will be seen from Fig. 11, the relation between the time of commencement of the principal portion (1st phase) and the epicentral distance was very nearly linear, for the limits of the latter under consideration, namely, about 40° and 130°.

As with the other velocities, v_3 calculated by "direct method" increased with the epicentral distance, the mean values being as follows :—

(i), (ii), and (iii)........$x=$ 49°43′; $v_3=3.94$ km/sec.
(iv) and (v) ....$x=$113 09 ; $v_3=4.32$ „

The relation to the epicentral distance of the velocity v_3 is illustrated in Fig. 12.

TABLE XIV. v_3 calculated by "Difference Method."

Combination of Stations.	Distance Difference $=\delta x$.	Time Difference $=\delta t_3$	v_3
Tacubaya —{Cheltenham. Washington.	128°47′−105°20′=23°27′	sec. 490	km/sec. 5.31
„ — Birmingham.	„ − 58 49 =69 58	1,632	4.75
„ — (ii)	„ − 50 17 =78 30	1,815	4.81
„ — Taihoku.	„ − 39 27 =89 20	2,095	4.74
Cheltenham Washington } —Birmingham.	105 20 − 58 49 =46 31	1,142	4.52
„ —(ii)	„ − 50 17 =55 03	1,325	4.62
„ —Taihoku.	„ − 39 27 =65 53	1,605	4.56
Birmingham —(ii)	58 49 − 50 17 = 8 32	185	5.15
„ —Taihoku.	„ − 39 27 =19 22	463	4.64
(ii) — „	50 17 − 39 27 =10 50	280	4.31

In the 10 combinations of the different stations given in the above table, the velocity v_3 varied between 4.31 and 5.31 km/sec. Excepting the 9th combination, for which the time difference δt_3 was too short, we obtain the following mean value of the velocity :—

$$v_3=\mathbf{4.70}\ \text{km/sec.}$$

The increase of the velocity with the epicentral distance is in this case very slight.

115. *Transit Velocity (v_5) of the 3rd Phase of Principal Portion.* The 5th section, or the 3rd phase of the principal portion has been identified in the seismograms obtained at Taihoku, Manila, Tadotsu, Ōsaka, Tōkyō, Leipzig, Göttingen, Quarto-Castello, Querce, Ximeniano, Birmingham, Cheltenham, Washington, and Tacubaya. Table XV gives, for each of these 12 stations, the epicentral distance (x), the time (t_5) of commencement of the 3rd phase of principal portion; the velocity v_5 calculated according to the "direct method" being also indicated.

TABLE XV. Observation of the 3rd Phase of Principal Portion; v_5 Calculated by "Direct Method."

Station.	Epicentral Distance $=x$.	Time of Commencement of 3rd Ph., Principal Portion $=t_5$.	t_5-t_0	v_5 calculated by "Direct Method"
Eqke. Origin.	......	h m s [0 49 48]	—	—
Taihoku (Formosa).	39° 27′	1 13 19	23m 31s	3.11 km/sec.
Manila.	43 34	1 16 15	26 27	3.05
Tadotsu.	47 02	1 18 52	29 04	3.00
Osaka.	48 19	1 19 52	30 04	2.98
Mean	**47 41**	**1 19 22**	**29 34**	**2.99**
Leipzig.	50 16	1 20 05	30 17	3.08
Tokyo: EW Component.	51 26	1 22 26	32 38	2.98
Tokyo: Tromometer (Hongo)		1 21 22	31 34	
Tokyo: " (Central Met. Observatory.)		1 21 40	31 52	
Querce	51 54	1 20 09	30 21	3.17
Quarto-Castello	51 56	1 20 54	31 06	3.09
Göttingen.	51 45	1 20 18	30 30	3.14
Ximeniano.	51 55	1 20 01	30 13	3.18
Mean	**51 31**	**1 20 52**	**31 04**	**3.07**

Station.	Epicentral Distance $=x$.	Time of Commencement of 3rd Ph., Principal Portion $=t_5$.	t_5-t_0	v_5 calculated by "Direct Method."
		h m s	m s	km/sec.
Birmingham.	58° 49′	1 25 22	35 34	3.06
Washington, D.C.	105 17	1 51 17	61 29	3.17
Cheltenham.	105 22	1 51 10	61 22	3.18
Mean	**105 20**	**1 51 14**	**61 26**	**3.18**
Tacubaya.	128 47	2 01 49	72 01	3.31

TABLE XVI. v_5 calculated by "Difference Method."

Combination of Stations.		δx	δt_5	v_5
			m s	km/sec.
Tacubaya	-Washington. Cheltenham.	23° 27′	10 35	4.10
„	-Birmingham.	69 58	36 27	3.55
„	-Leipzig. Tōkyo. Florence. Göttingen.	77 16	40 57	3.49
„	-Ōsaka, Tadotsu.	81 06	42 27	3.54
„	-Manila.	85 13	45 34	3.46
„	-Taihoku.	89 20	48 30	3.41
Washington Cheltenham	-Birmingham.	46 31	25 52	3.33
„	-Leipzig. Tōkyo. Florence Göttingen	53 49	30 22	3.28
„	-Ōsaka, Tadotsu.	57 39	31 52	3.35
„	-Manila.	61 46	34 59	3.27
„	-Taihoku.	65 53	37 55	3.22

Combination of Stations.		δx	δt_s	v_s
			m s	km/sec
Birmingham	-{ Leipzig. Tōkyo. Florence. Göttingen	7° 18′	4 30	3.00
,,	-Ōsaka, Tadotsu.	11 08	6 00	3.44
,,	-Manila.	15 15	9 07	3.10
,,	-Taihoku.	19 22	12 03	2.98
Leipzig Tōkyo Florence Göttingen }	-Ōsaka, Tadotsu.	3 50	1 30	4.73
,,	-Manila.	7 57	4 37	3.19
,,	-Taihoku.	12 04	7 33	2.96
Ōsaka, Tadotsu	-Manila.	4 07	3 07	2.44
,,	-Taihoku.	8 14	6 03	2.52
Manila	-Taihoku.	4 07	2 56	2.60

The mean of all the 21 values of v_s contained in the preceding table is :—

$$v_5 = \mathbf{3.28} \text{ km/sec.};$$

the epicentral distances of the stations taken into consideration being from 39° 27′ to 128° 47′.

116. ***Transit Velocity (v_m) of the Vibrations corresponding to the Absolute Maximum in Milne Seismogram.*** The maximum in a Milne horizontal pendulum seismogram does not generally constitute the most active part of the real earthquake motion, being the effect due to the proper instrumental oscillations. As the natural period of a Milne seismograph is usually set at about 15 seconds, the maximum in question probably corresponds to the middle part of the 6th section, or the 4th phase of the principal portion, in which, according to § 8 (p. 16), the predominating period is P_3 and whose amplitude is large and equal to about $\frac{2}{3}$ of that in the preceding phase. The following table is based on the data given in Professor Milne's Circular, No. 13, epitomized in the table given in § 65.

TABLE XVII. Milne Horizontal Pendulum Observations of the "Absolute Maximum."

Station.	Epicentral Distance $=x$.	Time of occurrence of Absol. Max. $=t_m$	$t_m - t_0$	v_m calculated by "Direct Method."
		h m s	m	km/sec.
EQ. Origin.	....	[0 49 48 $=t_0$]		
		h m		
Bairût.	34° 41′	1 24.5	34.7	1.85
Kew.	58 05	1 29.2		
Edinburgh.	58 48	1 31.5		
Shide.	58 52	1 30.0		
Liverpool.	59 18	1 30.6		
Paisley.	59 30	1 30.7		
Mean.	....**58 55**	**1 30.4**	**40.6**	**2.69**
San Fernando.	66 54	1 34.0	44.2	2.80
Ponta Delgada.	79 54	1 54.5		
Cape Town.	85 46	1 46.0		
Mean.	....**82 50**	**1 50.25**	**60.5**	**2.53**
Victoria, B.C.	97 42	1 57.1		
Toronto.	101 30	1 54.3		
Baltimore.	104 47	2 10.0		
Mean.	...**101 20**	**2 0.5**	**70.7**	**2.65**

Average (Bairût excepted)....................**2.67**

The mean value of the velocity v_m is thus **2.67** km/sec., agreeing fairly well with the value of the transit velocity of the 4th phase of the principal portion, previously obtained, namely $v_6=2.8$ km/sec.*

117. *Remarks on v_3 and v_5 calculated by "Direct Method."*

v_3 As shown in Fig. 12 and Table XIII (p.170), there seems to be a slight increase with the radial distance of the velocity (v_3) of the 1st phase of the principal portion; varying between 3.83 km/sec. for Taihoku ($x=39°\ 27'$) to 4.42 km/sec. for Tacubaya ($x=128°\ 47'$). The average rate of increase of the v_3 between the the distance limits under consideration is about 0.00686 km per degree.

Comparing the observation at the Japanese stations with those at the Middle Europe stations, we have :—

(i) Tôkyo, Ōsaka, Tadotsu......*mean* $x=48°\ 56'$; $v_3=3.82$ km/sec.

(ii) Leipzig, Rocca di papa, Göttingen, Quarto-Castello............ $x=51°\ 18'$; $v_3=3.95$ km/sec.

The differences of the x and v_3 between (i) and (ii) are as follows:—

(ii)-(i)......$\delta x=2°\ 22'$; $\delta v_3=0.13$ km/sec.

Now, according to the average rate of velocity increase as above mentioned, the increase in v_3 corresponding to $\delta x=2°\ 22'$ ought to be about 0.016 km/sec. Thus, if the identification of the commencement of the 1st phase of the principal portion in the different seismograms be supposed to be correct, then the velocity v_3 for Japan was slightly slower than that along the path to the Middle Europe.

v_5 According to Fig. 14 and Table XV (p.172), the velocity (v_5) of the 3rd phase of principal portion remained, for the epicent-

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* The *Publications*, No. 23.

Fig 11. Indian Earthquake of 1905. Relation to the Epicentral Distance of the Time of Commencement of the Principal Portion.

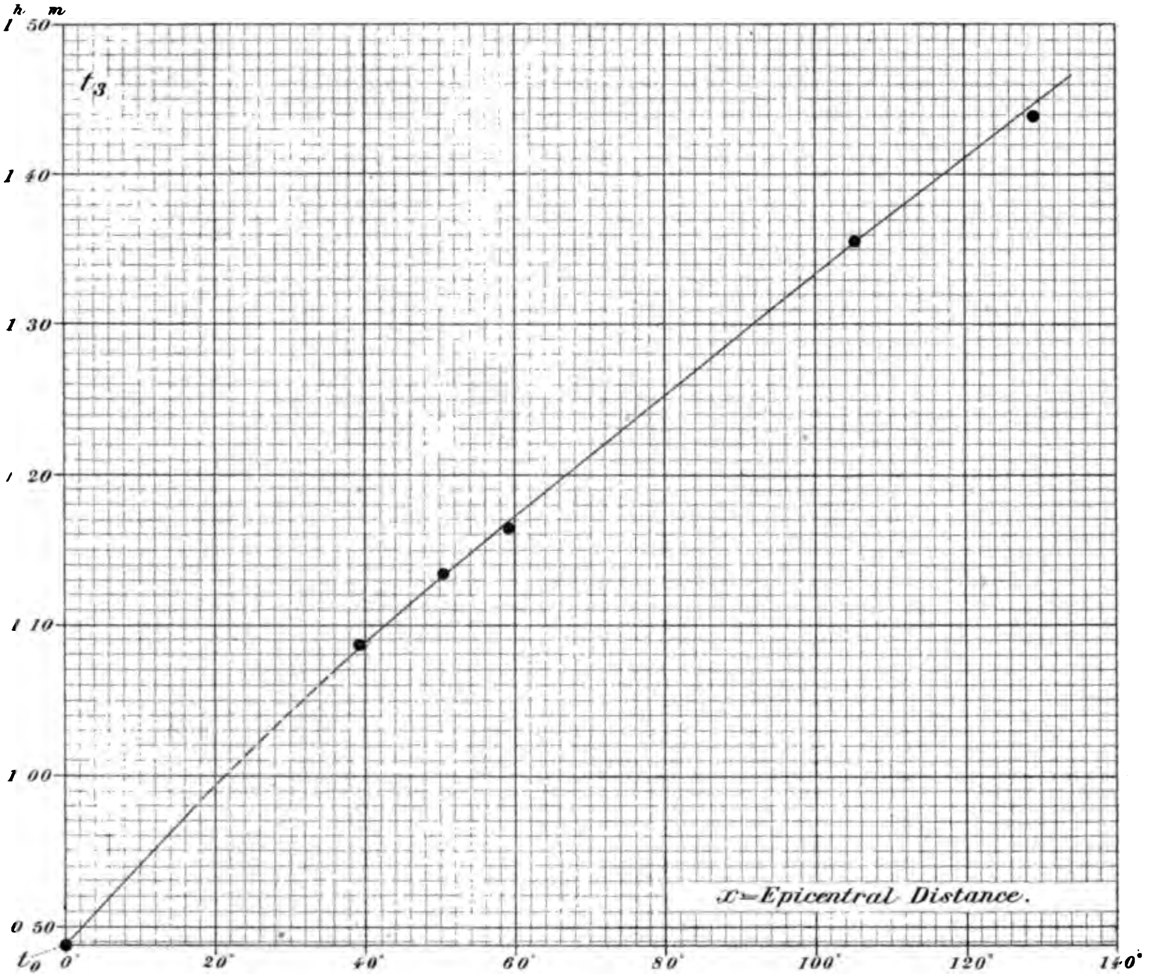


Fig. 12. Indian Eqke of 1905. Relation to the Epicentral Distance of the Velocity of the 1st Phase of the Princ. Portion, Calculated by "Direct Method."

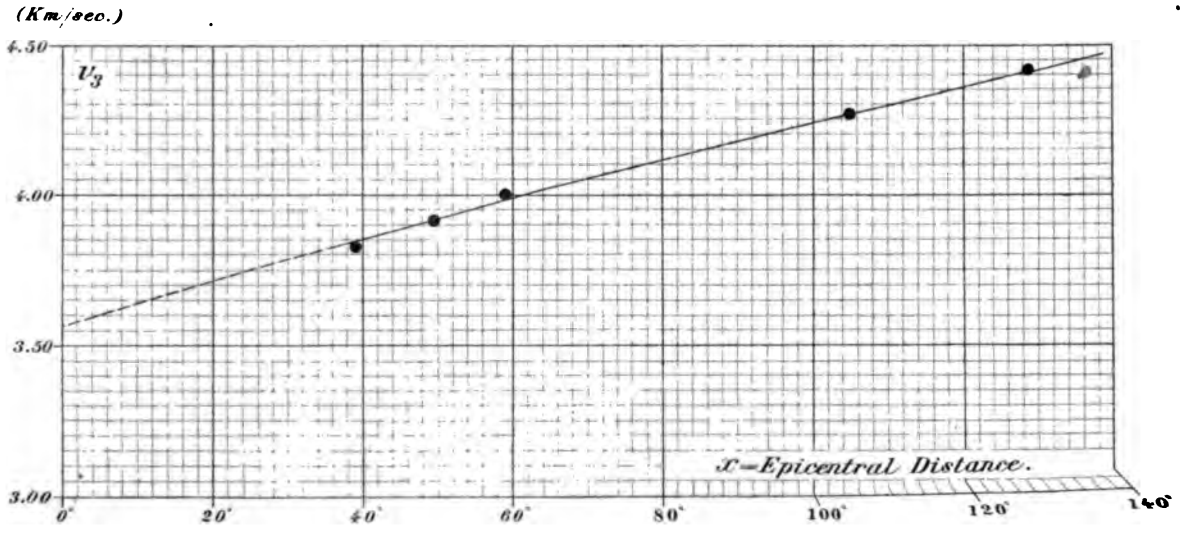


Fig. 13. Indian Eqke of 1905. Relation to the Epicentral Distance of the Time of Occurrence of the 3rd Phase of Principal Portion.

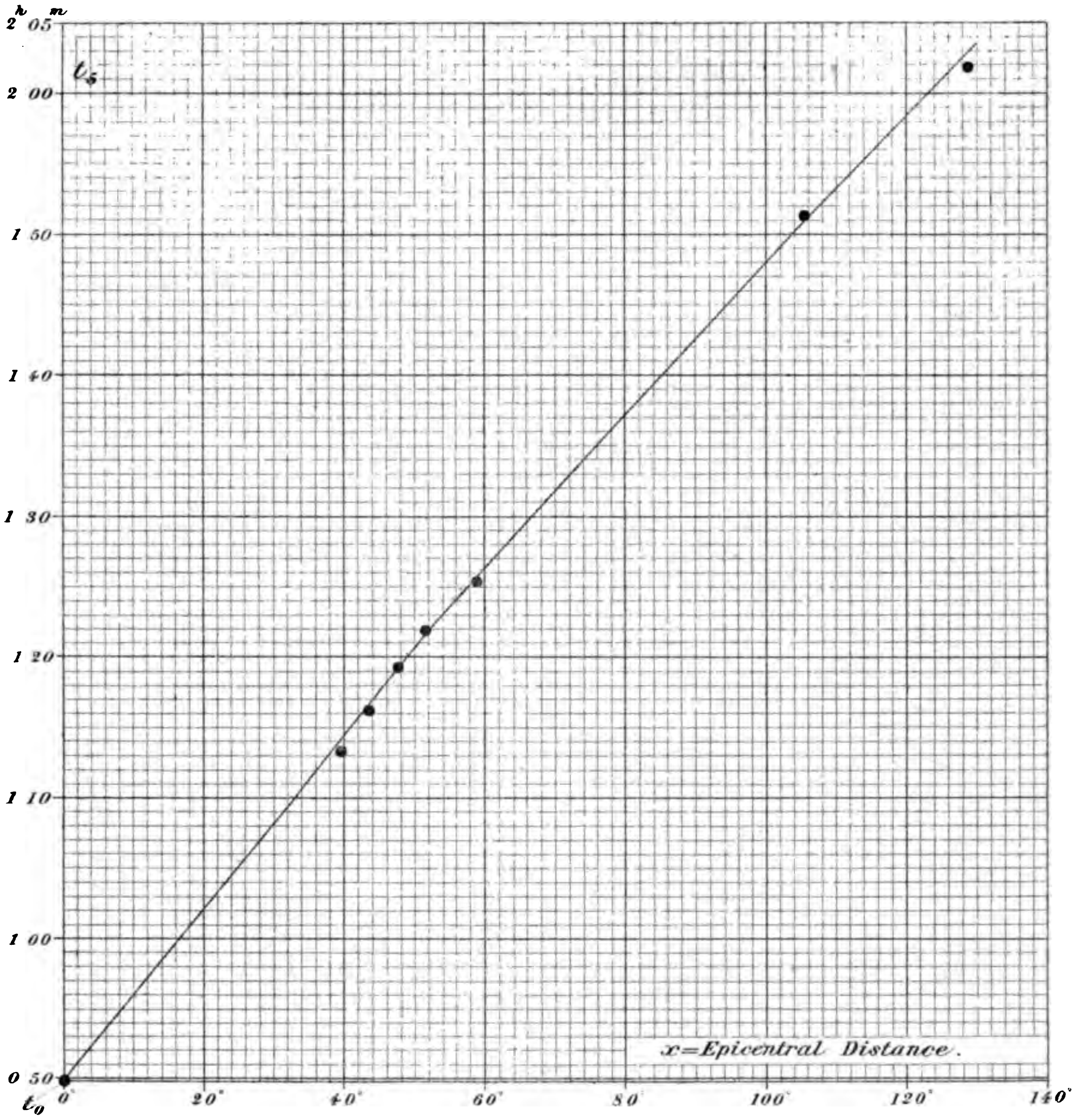


Fig. 14. Indian Eqke of 1905. Relation to the Epicentral Distance of the Velocity of the 3rd Phase of Princ. Portion, Calculated by "Direct Method."

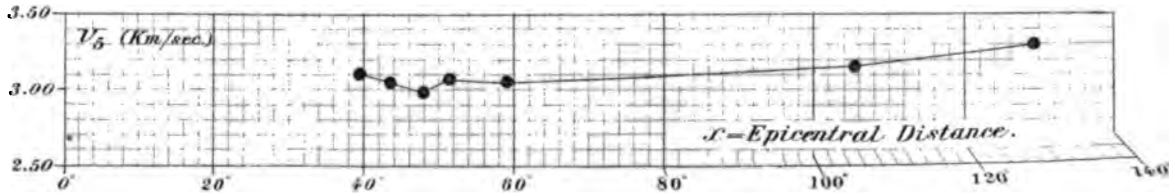
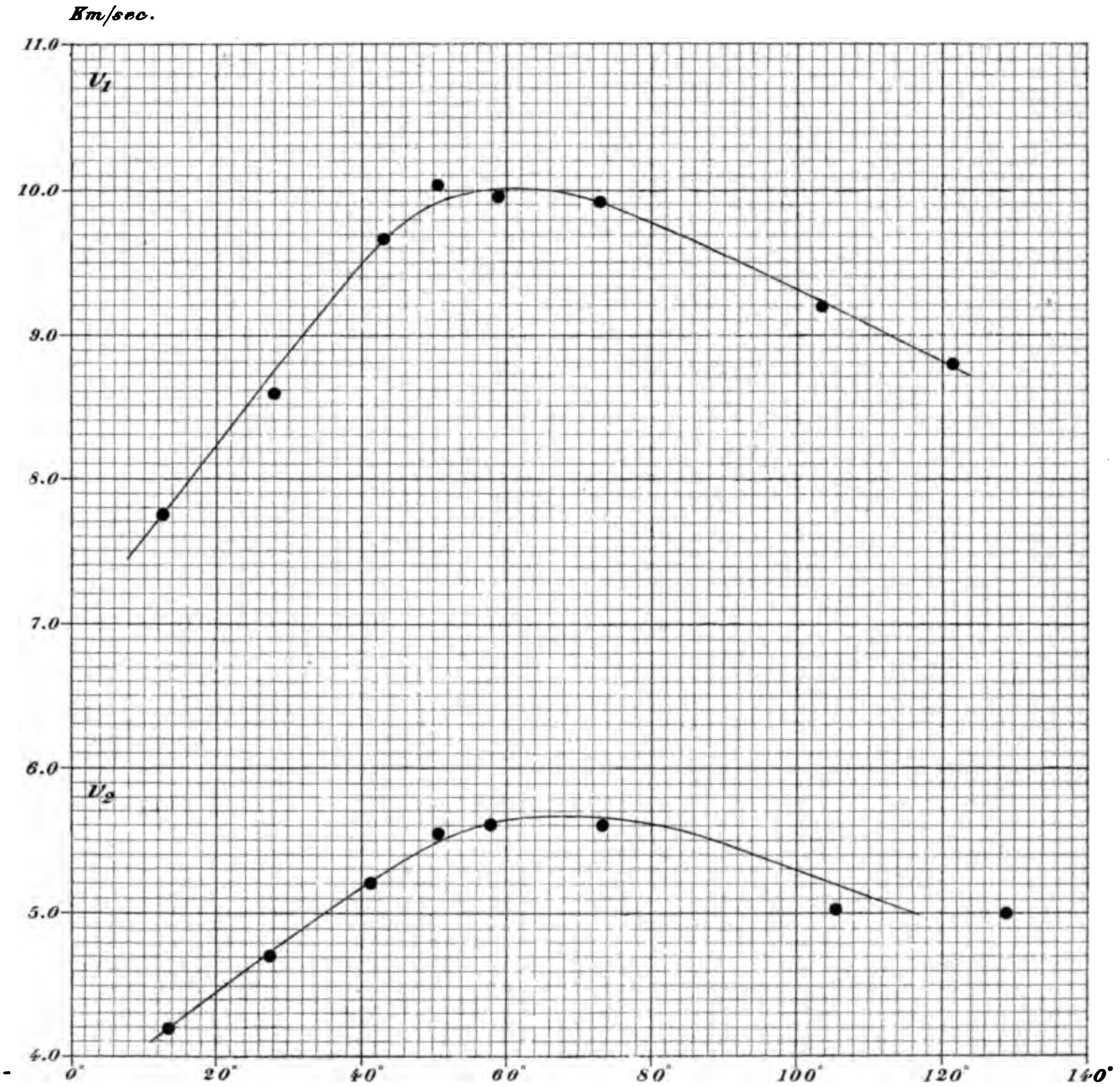


Fig. 15. Indian Earthquake of April 4, 1905.
Relation to the Epicentral *Chord* Distance of the Velocities of the 1st and 2nd Preliminary Tremors, Calculated by "Direct Method."



ral distance of 39° 27′ to 128° 47′, very nearly constant, varying only between 2.98 km/sec. (Japan) and 3.31 km/sec. (Tacubaya). The average of all the values of the velocity given in Table XV is v_3=**3.11** km/sec.

Comparing the observations at the Japanese stations with those at the Middle Europe stations, we have :—

(i) Tadotsu, Osaka, Tokyo......*Mean* x=49° 56′; v_5=2.98 km/sec.
(ii) Leipzig, Göttingen, Querce, Quarto-Castello, Ximeniano, ...*Mean* x=51° 33′; v_5=3.13 km/sec.

The velocity v_5 for the Middle Europe is thus 0.15 km/sec. greater than that for Japan.

v_5' The velocity (v_5') of the absolute maximum in the Milne horizontal pendulum seismograms seems, according to Table XVII, to be practically constant for the distances x=58° 55′ to x=101° 20′.

Appendix to Chapter VI.

118. ***Transit Velocities calculated according to the supposition of the Propagation along the Chord.*** The velocity calculations given in Chapters IV to VI are based on the supposition of the propagation of seismic waves along the arcual path or the great circle joining a given observing station with the origin of disturbance. The results thus obtained are simpler than those obtained on the supposition of the earthquake propagation along the chord.

The following table gives the mean values of the transit velocities v_1 and v_2 for the different groups of stations, calculated by the "direct method" under the supposition of the chord transmission.

TABLE XVIII. v_1 and v_2 Calculated by "Direct Method."

Stations.	Mean Epicentral Distance $= x$	v_1 (Along Chord)	v_2 (Along Chord)
		km sec.	km sec.
Taschkent, Colaba.	12° 24′	7.76	—
Colaba, Barrackpore, Calcutta.	13 34	....	4.20
Irkutsk, Tiflis, and 5 other Caucasian Stations.	27 42	....	4.71
Tiflis, Irkutsk.	27 57	8.59	—
Taihoku, Jurjew, Manila.	41 57	....	5.23
Taihoku, Jurjew, Manila, Belgrade, Krakau.	43 22	9.66	—
Tadotsu, Upsala, Kōbe, Ōsaka, Laibach, Messina, Potsdam, Triest, Pola, Leipzig, Ischia, Jena, Rocca di papa, Padova, Tokyo, Mizusawa, Göttingen, Querce, Ximeniano, Quarto-Castello.	50 12	....	5.54
Same as above, with the exception of Tadotsu, and with the addition of Hamburg and Strassburg.	50 24	10.04	—
Mauritius, Birmingham, Paisley.	58 06	....	5.62
Shide, Kew, Birmingham, Liverpool, Paisley, Edinburgh.	58 54	9.95	—
San Fernando, Cape Town.	73 11	9.92	5.62
Toronto, Victoria, B.C., Washington, Cheltenham.	103 03	9.22	—
Cheltenham, Washington.	105 20	....	5.02
Christchurch, Wellington, Porto Rico, Tacubaya.	121 21	8.80	—
Tacubaya.	128 47	....	5.00

Thus, according to the supposition of the chord transmission the velocities v_1 and v_2, calculated by "direct method," show each the maximum at an epicentral distance of $x=50°$ to $60°$, as illustrated in Fig. 15, Pl. VIII; the greatest values of the v_1 and v_2 being 10.03 and 5.62 km/sec. The greatest values of the two velocities calculated by "direct method" on the supposition of the *arcual* transmission are 10.79 and 6.23 km/sec., respectively.

The existence of the maximum in the value of each of the two velocities v_1 and v_2 calculated by the "direct method" seems to indicate the absurdity of the supposition of the chord transmission of the vibrations composing the 1st and 2nd preliminary tremors of the teleseismic motion.

Chapter VII. Duration of the 1st Preliminary Tremor.

119. ***Observations at the Different Stations.*** The duration (y_1) of the 1st preliminary tremor for each of the 37 different stations or group of stations is given in Table XIX, the longest value being $17^m\ 10^s$ for Apia and Tacubaya, whose mean x is $121°\ 58'$.

TABLE XIX. Duration of the 1st Preliminary Tremor.

Station.	Epicentral Distance $=x$.		Duration of 1st Prel'nary Tremor $=y_1$.	
Taschkent.	11°	20′	2^m	05^s
Colaba (Bombay).	13	28	3	31
Calcutta.	13	42	3	09
Mean................	**13**	**35**	**3**	**20**

Station.	Epicentral Distance $=x$.		Duration of 1st Prel'nary Tremor $=y_1$.	
Kodaikanal.	21°	35′	3^m	55^s
Tiflis.	27	26	4	43
5 Caucasian Stations.*	27	11	4	41
Mean................	**26**	**10**	**4**	**33**
Taichu.	39	051	6	14
Tainan.	39	06	6	15
Taihoku.	39	27	6	06
Batavia.	42	35	7	00
Manila.	43	34	6	38
Mean................	**40**	**45**	**6**	**27**
Tadotsu.	47	02	7	00
Upsala.	47	41	6	57
Kōbe.	48	03	7	00
Ōsaka.	48	19	7	12
Laibach.	49	19	7	17
Messina.	49	46	7	15
Potsdam.	49	48	7	05
Triest.	49	52	7	00
Pola.	49	55	7	14
Leipzig.	50	16	7	09
Ischia.	50	30	7	18
Rocca di papa.	51	15	7	18
Tokyo.	51	26	7	17
Mizusawa.	51	39	7	20
Göttingen.	51	45	7	17
Querce.	51	54	7	16
Ximeniano.	51	55	7	14

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* Achalkalaki, Batum, Borshom, Derbent, Schemacha.

Station.	Epicentral Distance $=x$.		Duration of 1st Prel'nary Tremor $=y_1$.	
Quarto Castello.	51°	56′	7^{m}	15^{s}
Mean................	**50**	**12**	**7**	**11**
Mauritius.	55	15	8	09
Birmingham.	58	49	8	21
Paisley.	59	30	8	18
Mean................	**57**	**51**	**8**	**16**
Cape Town.	85	46	9	57 (?)
Cheltenham.	105	22	14	44
Washington, D.C.	105	17	15	12
Mean................	**105**	**20**	**14**	**58**
Apia (Samoa).	115	08	17	42
Tacubaya.	128	47	16	38
Mean................	**121**	**58**	**17**	**10**

Comparing the observations at the Japanese stations with those at the Middle Europe stations, we obtain the following results :—

(i) *Japan* :—Tadotsu, Kōbe, Ōsaka, Tokyo, Mizusawa............
Mean $x=49^{\circ}\,39'$, $y_1=7^{m}\,11^{s}$.
Middle Europe :—Upsala, Laibach, Messina, Potsdam, Triest, Pola, Leipzig, Ischia, Rocca di papa, Göttingen, Querce, Ximeniano, Quarto-Castello........................
Mean $x=50^{\circ}\,27'$, $y_1=7^{m}\,12^{s}$.

Again, taking only those stations, whose epicentral distance is about $51^{\circ}\frac{1}{2}$, we obtain the following results :—

(ii) *Japan*:—Tokyo, Mizusawa........*Mean* $x=51°\ 30'$, $y_1=7^m\ 18^s$.
Middle Europe: Leipzig, Ischia, Rocca di papa, Göttingen, Querce, Ximeniano, Quarto-Castello..................
Mean $x=51°\ 22'$, $y_1=7^m\ 15^s$.

According to (i), the duration y_1 was the same for the Japanese stations and those of Middle Europe, the mean distance for the former group being nearly 50′ greater than for the latter. But according to (ii), the mean values of y_1 and x for the two Japanese stations of Tokyo and Mizusawa were very nearly the same as those for 7 German and Italian stations. From this it may be conjectured that the relation between x and y_1 depends only slightly on the nature of the path of the earthquake propagation.

120. ***Relation between the Epicentral Distance and the Duration of the 1st Preliminary Tremor.*** According to Table XIX, the mean group values of the epicentral distance (x) and the corresponding duration (y_1) of the 1st preliminary tremor are as follows:—

(i)	$x=11°\ 20'$....	$y_1=2^m\ 05^s$	(1 station)
(ii)	13 35	3 20	(2 stations)
(iii)	26 10....	4 33	(7 „)
(iv)	40 45	6 27	(5 „)
(v)	50 12	7 11	(18 „)
(vi)	57 51	8 16	(3 „)
(vii)	105 20	14 58	(2 „)
(viii)	121 58	17 10	(2 „)

The variation of y_1 with x is illustrated in Fig. 16, from which it will be seen that the relation between the two quantities, for the group values of (iii) to (viii), may approximately be represented by a straight line. Assuming, therefore, a linear equation between x and y_1 for the limits under consideration, and calculating by

Method of Least Squares the values of the constants, we obtain :—

(1)..........$x^{\mathrm{km}} = \mathbf{13.77}\ y_1^{\mathrm{sec.}} - \mathbf{576}^{\mathrm{km}}$

The above equation, which is to be regarded as applicable for x between about 20° and 120°, refers to the observations at different stations of the Kangra Eathquake, and differs from the formulae given in the *Publications*, Nos. 5 and 13, which related to different earthquakes observed in Tokyo.

121. ***Comparison with the Turkestan and San Francisco Earthquakes.*** Comparing the relations between the x and y_1 obtained for the Indian earthquake with those obtained for the Turkestan (Kashgar) earthquake of 1902 and the San Francisco earthquake of 1906, we have :—

(1) **Indian Earthquake**........$x^{\mathrm{km}} = 13.77\ y_1^{\mathrm{sec.}} - 576^{\mathrm{km}}$
(2) **Turkestan** „ *........$x = 11.80\ y_1 - 60$
(3) **San Francisco** „ †........$x = 16.79\ y_1 - 1618$

The equations (2) and (3) were obtained from the observations at different seismological stations, relating respectively to the Turkestan and San Francisco earthquakes. It thus seems that the relation between the x and y_1 is not the same for different earthquakes. Of the above three equations, (2) is to be taken as of less value than the two others, being based on a less number of observations. Supposing the weight of the two equations (1) and (3) to be double that of (2), and taking the averages I obtain the following provisional result :—

(4)..........$x^{\mathrm{km}} = \mathbf{14.58}\ y_1^{\mathrm{sec}} - \mathbf{890}^{\mathrm{km}}$

which is to be regarded as holding good for x between about 20° and 140°.

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* See the *Bulletin*, Vol. I, No. 4.
† „ „ „ , Vol. I, No. 1.

122. ***Comparison with Earthquakes of Near Origin.*** According to the results of the observations in Tokyo of the large teleseismic disturbances mentioned in § 8, the durations of the 1st and 2nd preliminary tremors are in the ratio of 100 to 95. Hence if y denote the total duration of the 1st and 2nd preliminary tremors, Equation (4) of the preceding § is transformed into the following:—

$$(5)\dots\dots\dots x^{km}=7.06\,y^{sec.}-576^{km},$$
$$\text{for}\quad 2000^{km}< x < \text{about } 16{,}000^{km}$$

Now, for the earthquakes of near origins observed in Tokyo, whose distance varied between 70 and 900 km, the relation between the epicentral distance (x) and the total duration (y) of the preliminary tremors were as follows*:—

$$(6)\dots\dots\dots x^{km}=7.27\,y^{sec.}+38^{km},$$
$$\text{for}\quad 70^{km}< x < 900^{km}$$

Thus we see that the rate of increase of the epicentral distance for 1 second of the duration of the preliminary tremor is practically the same for distant and near earthquakes, as follows:

$$\begin{cases}\text{Distant Eqs.}\dots\dots\dfrac{dx}{dy}=7.06\text{ km}\\ \text{Near Eqs.}\dots\dots\dots\ \text{,,}\ =7.27\ \text{,,}\end{cases}$$

This fact probably indicates that the *rate* of separation with increase of the epicentral distance of the successive phases of the seismic motion is nearly the same for earthquakes of near and distant origins, within the limits of x under consideration.

The cases of those earthquakes, whose epicentral distance (x) is less than 70 or 100 km, must be treated specially.

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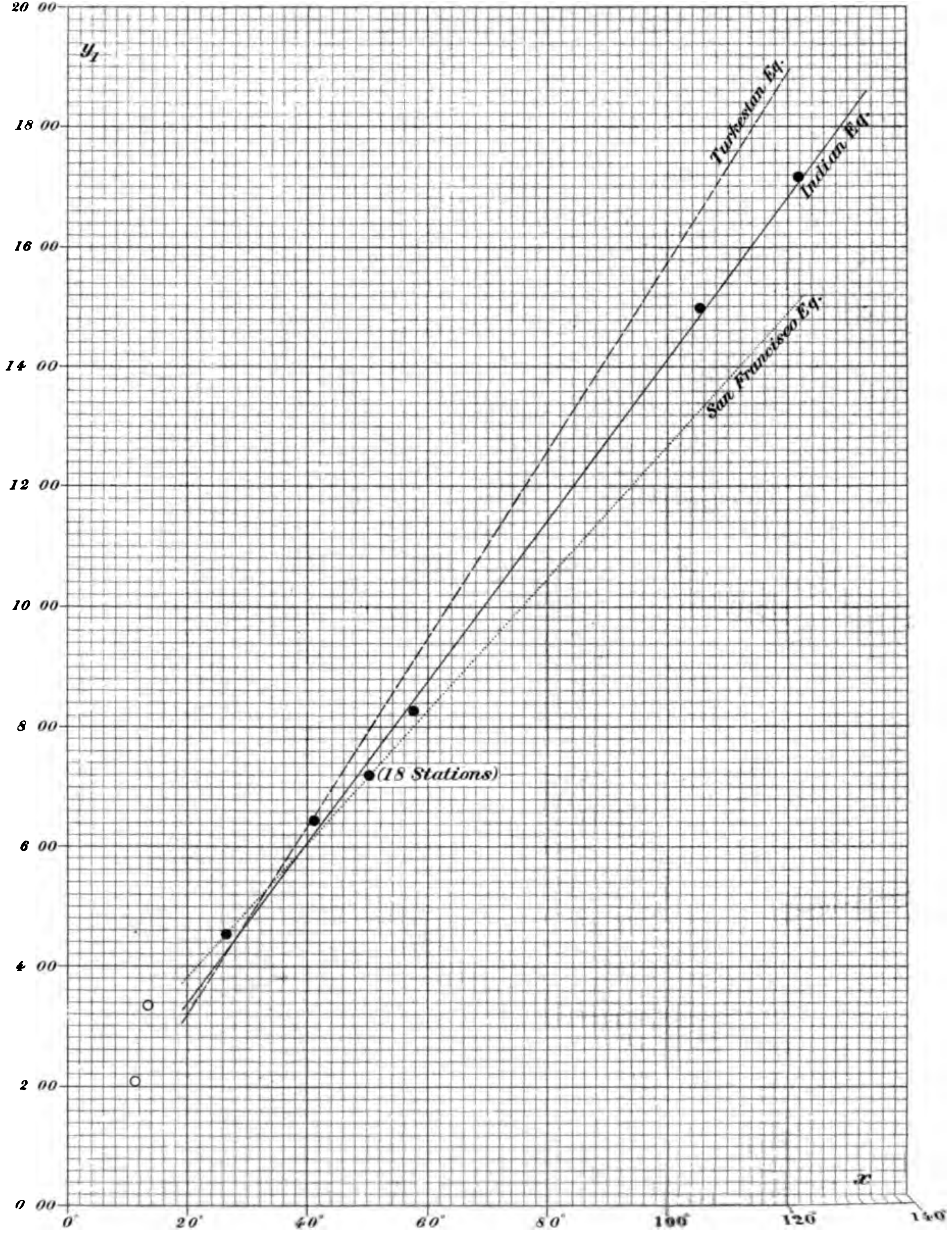
* The *Publications*, No. 13.

Pl. IX.

Fig. 16. Relation of the Duration of the 1st Preliminary Tremor to the Epicentral Distance.

The black dots (●) refer to Indian Eqke; 2 small white circles, which also refer to the same eqke (for Taschkent and 2 Indian Stations of Colaba and Calcutta) may relate to the total prel. tremor.



Pl. X.

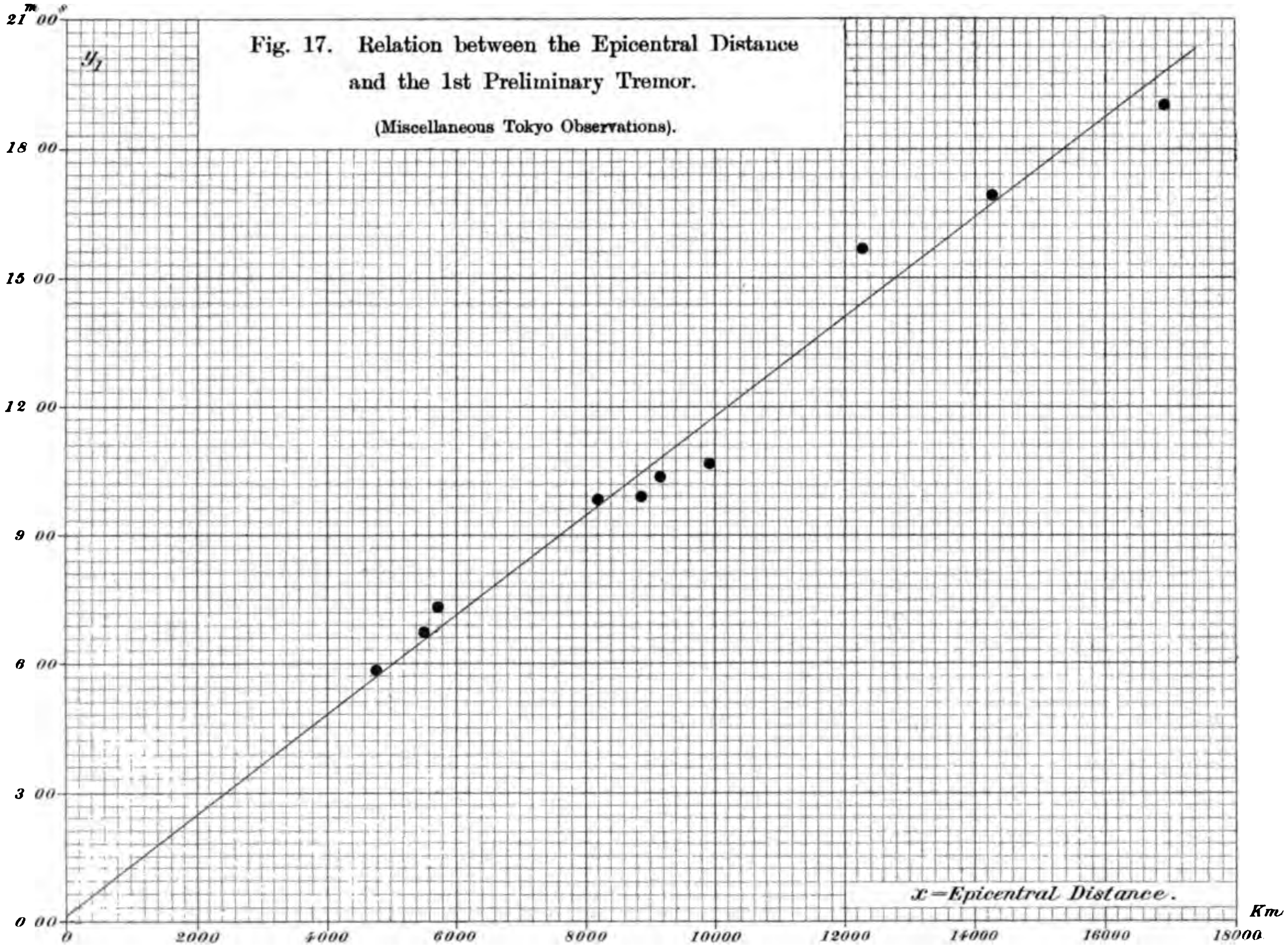


Fig. 17. Relation between the Epicentral Distance and the 1st Preliminary Tremor.

(Miscellaneous Tokyo Observations).

123. ***Relation between x and y_1 based on the Tokyo Observations of different Teleseismic Disturbances.*** Let us finally consider, for the sake of reference, the relation between the duration (y_1) of the 1st preliminary tremor and the epicentral distance (x), based on the horizontal pendulum observations at Tokyo of the following 10 large teleseismic disturbances, whose origins are more or less definitely known.

TABLE XX. Miscellaneous Observations in Tokyo.

Earthquake.	Date.	Time of Occurrence in Tokyo $=t_1$ (G.M.T.)	Position of Eqke Origin.		Epicentral Distance $=x$	Duration of 1st Prel. Tremor $=y_1$.
			Latitude.	Longitude.		
		h m s				m s
Ceram.	Sept. 29, 1899.	17 11 00	6° 00′ S	129° 00′ E	42° 56′	5 46
Turkestan.	Aug. 22, 1902.	3 09 33	39 42 N	76 00 E	49 32	6 44
India.	April. 4, 1905.	0 59 08	31 49 N	77 00 E	51 26	7 17
San Francisco.	April. 18, 1906.	13 24 35	38 15 N	123 00 W	73 41	9 49
North Japan.*	Feb. 19, 1897.	21 01 05	38 30 N	143 30 E	79 26	9 55
Calabria.	Sept. 8, 1905.	1 56 09	38 50 N	16 16 E	89 02	10 41
Aidin.	Sept. 20, 1899.	2 24 27	37 50 N	29 00 E	82 29	10 19
Guatemala.	April. 19, 1902.	2 38 47	14 30 N	91 15 W	110 23	15 40
Caracas.	Oct. 29, 1900.	9 31 52	10 00 N	68 00 W	127 19	15 55
Valparaiso.	Aug. 17, 1906.	1 00 34	31 00 S	73 00 W	152 22	18 59

The relation between the t_1 and x is, as is graphically shown in Fig. 17, very irregular, due probably to some variation in the values of the constants characterizing the linear equation for each of the different earthquakes. Calculating the constants by Method of Least Squares from the results of the observations contained in the above table we obtain :—

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* This earthquake was observed at Potsdam by the present author with Rebeur Horizontal Pendulum, the time (t_1), and the duration (y_1) of the 1st preliminary tremor are the values relating to Potsdam.

$$(7)\ldots\ldots\ldots\ldots x^{\mathrm{km}} = \mathbf{14.42}\, \overset{\mathrm{sec.}}{y_1} - \mathbf{148}^{\mathrm{km}},$$

$$\text{for} \quad 40^\circ < x < \text{about } 150^\circ;$$

This formula, which is a revised form of that first given in the *Publications*, No. 5, may be regarded as being applicable to the observations made in Japan. Equation (4) given in the preceding § is to be regarded as expressing the approximate mean relation between the x and y_1 for different stations.

Chapter VIII. Periods of Vibration.

124. ***Quarto-Castello and Birmingham.*** By way of illustration let us examine the periods of vibration occurring in the Quarto-Castello and Birmingham diagrams, which were furnished by Stiattesi and Omori seismographs respectively (§§ 29 and 33). In the subsequent tables, the periods more frequently occurring are given in fat prints.

TABLE XXI. Periods of Vibration at Birmingham.

1st. prel. Tremor.	2nd prel. Tremor.	1st and 2nd Ph., P.P.	3rd Phase, Princ. Port.	4th Phase, Princ. Port.	End Portion.	Mean.
sec.	sec.	sec.	sec.	sec.	sec.	sec.
4.6	4.6	—	—	—	—	**4.6**
7.1	—	7.5	—	—	—	**7.3**
—	9.7	9.9	—	9.7	10.4	**9.9**
12.0	—	—	—	12.3	—	**12.2**
—	15.5	—	—	14.7	14.3	**14.8**
—	—	18.8	17.9	—	16.7	**17.8**
—	—	—	31.4*	—	—	31.4*
—	—	36.6	—	—	—	36.6

(*Due to proper pendulum motion.)

TABLE XXII. Periods of Vibration at Quarto-Castello.

1st Preliminary Tremor.	2nd Preliminary Tremor.	1st and 2nd Ph. Princ. Portion.	3rd Phase, Princ. Portion.	Later Ph. of Princ. Port. End Portion.	Mean.
sec. **4.3**	sec. **4.8**	sec. 4.9.	sec. —	sec. **4.9**	sec. **4.7**
6.4	—	—	6.9	—	**6.7**
9.1	**8.6**	**9.1**	**10.0**	9.1	**9.2**
—	11.1	—	—	12.1	**11.6**
—	—	—	**15.0**	**14.5**	**14.8**
—	—	—	—	**16.7**	**16.7**
—	—	—	—	**18.8***	**18.8**
—	—	—	26.6	—	26.6
—	—	29.8	—	—	29.8
—	—	50.0	—	—	50.0
—	54.5	—	—	—	54.5

Comparing Tables XXI and XXII, we see that nearly all of the different periods at Birmingham are to be found also at Qnarto-Castello. Again, from Table XXII it will be seen that the two periods of mean values of 4.7 and 9.2 sec. occurred in the successive phases of the Quarto-Castello seismogram. The two corresponding periods, whose mean values are 4.6 and 9.9 sec. respectively, also occurred in most of the different phases of the Birmingham seismogram.

125. ***Taihoku, Taichu, Tainan.*** Table XXIII gives the period (T) and the maximum range ($2a$) in each of the successive epochs of the earthquake motion registered at the three Formosan stations of Taihoku, Taichu, and Tainan (§§ 25, 26, and 27). The observations at theses places may be regarded as examples of the seismic records furnished by horizontal pendulums of comparatively short period.

TABLE XXIII. T and $2a$ observed at 3 Formosan Stations of Taihoku, Taichu, and Tainan. EW Component Seismograms.

	Taihoku.		Taichu.		Tainan.	
	[1st Preliminary Tremor.]					
	Duration $= 6^{m}\ 6^{s}$		Duration $= 6^{m}\ 14^{s}$		Duration $= 6^{m}\ 15^{s}$	
	$T = 1.07^{\text{sec.}}$	$2a =$ —	$T =$ —	$2a =$ —	$T =$ —	$2a =$ —
	2.10 „	—	—	—	—	—
	3.30 „	—	—	—	—	—
	4.3 „	0.06^{mm}	$4.5^{\text{sec.}}$	0.17^{mm}	$4.0^{\text{sec.}}$	0.12^{mm}
	—	—	5.8 „	—	—	—
	—	—	—	—	13.8 „	0.08 „
	[2nd Preliminary Tremor.]					
	Duration $= 5^{m}\ 25^{s}$		Duration $= 5^{m}\ 10^{s}$		——	
	$T = 4.5^{\text{sec.}}$	$2a = 0.1^{\text{mm}}$	$T = 4.9^{\text{sec.}}$	$2a = 0.33^{\text{mm}}$	$T =$ —	$2a =$ —
	—	—	10.2 „	0.3 „	$12.1^{\text{sec.}}$	2.3^{mm}
	21 „	0.1 „	—	—	—	—
	[1st and 2nd Phases, Principal Portion.]					
	Duration $= 4^{m}\ 35^{s}$		Duration $= 4^{m}\ 50^{s}$		2nd prel. Trem., 1st and 2nd Ph., Princ. Portion....$9^{m}\ 46^{s}$.	
(i) During the first	......$2^{m}\ 24^{s}$......		......$2^{m}\ 9^{s}$......		..... ——	
	$T = 4.4^{\text{sec.}}$	$2a = 0.08^{\text{mm}}$	$T = 4.4^{\text{sec.}}$	$2a = 0.23^{\text{mm}}$	$T =$ —	$2a =$ —
	10.8 „	—	9.3 „	0.73 „	—	—
	41.2 „	0.22 „	—	—	—	—
(ii) During the next	......$2^{m}\ 11^{s}$......		......$2^{m}\ 41^{s}$......		—	—
	—	—	$4.6^{\text{sec.}}$	0.23^{mm}	—	—
	—	—	6.8 „	0.50 „	—	—
	—	—	10.0 „	2.0 „	$11.8^{\text{sec.}}$	4.6^{mm}
	—	—	16.5 „	—	15.3 „	—
	$30^{\text{sec.}}$	3.1^{mm}	—	—	—	—

	Taihoku.		Taichu.		Tainan.	
[3rd Phase, Principal Portion.]						
	Duration = 5^{m}	30^{s}	Duration = 5^{m}	40^{s}	——	
(i) During the first	...... 3^{m}	29^{s}	...... 1^{m}	44^{s}	......3^{m}	8^{s}
	$T=$ —	$2a=$ —	$T=9.0^{\text{sec.}}$	$2a=12.8^{\text{mm}}$	$T=11.8^{\text{sec.}}$	$2a=13.8^{\text{mm}}$
	$14.4^{\text{sec.}}$	11.9^{mm}	—	—	—	—
(ii) During the next	...... 2^{m}	1^{s}	...... 3^{m}	56^{s}		
	$5.7^{\text{sec.}}$	—	$5.0^{\text{sec.}}$	0.33^{mm}		
	11.8 ,,	2.05^{mm}	8.9 ,,	6.3 ,,		
	—	—	14.8 ,,	6.3 ,,		
[4th, etc., Phases, Principal Portion.]						
	——	....	..Duration = 3^{m}	5^{s} ..	..Duration = 6^{m}	2^{s}
	$T=$ —	$2a=$ --	$T=8.4^{\text{sec.}}$	$2a=1.2^{\text{mm}}$		
	—	—	—	—	$T=12.0^{\text{sec.}}$	$2a=6.8^{\text{mm}}$
	—	—	22.3 ,,	—		
End Portion.						
	$T=6.6^{\text{sec.}}$	$2a=$ —	$T=5.2^{\text{sec.}}$	$2a=0.17^{\text{mm}}$	—	—
	11.6 ,,	0.35^{mm}	8.9 ,,	0.5 ,,	—	—
	—	--	13.6 ,,	0.17 ,,	$T=13.0^{\text{sec.}}$	$2a=5.6^{\text{mm}}$

According to the above table, there is between the three stations often a marked difference in the amplitudes corresponding to a given period, being obviously the effect due to the difference in the amount of friction and the stability of the " steady mass " in the three seismographs.

The following table gives the results obtained by taking together the analyses contained in the preceding; the $2a$ is the maximum value corresponding to a given period in the three stations.

TABLE XXIV. 3 Formosan Stations. Elements of Motion.

1st Prel. Trem. Dur. = $6^{\rm m}12^{\rm s}$		2nd Prel. Trem. Dur. = $5^{\rm m}18^{\rm s}$		1st and 2nd Ph., Princ. Port. Dur. = $4^{\rm m}43^{\rm s}$		3rd Phase, Princ. Port. Dur. = $5^{\rm m}35^{\rm s}$		4th Phase, Princ. Port. Dur. = —		End Portion. —	
T	$2a$	T	$2a$	T	$2a$	T	$2a$	T	$2a$	T	$2a$
sec.	mm.	sec.	mm.	sec.	mm.	sec.	mm.	sec.	mm.	sec.	mm.
1.07	—	—	—	—	—	—	—	—	—	—	—
2.1	—	—	—	—	—	—	—	—	—	—	—
3.3	—	—	—	—	—	—	—	—	—	—	—
4.3	0.17	**4.7**	0.33	**4.5**	0.23	**5.4**	0.33	—	—	**5.9**	0.17
5.8	—	—	—	6.8	0.50	—	—	—	—	—	—
—	—	11.2*	2.3	**10.0**	2.0	**9.9**	12.8	8.4	1.2	**10.3**	0.5
13.8*	0.08	—	—	—	—	11.8*	13.8	12.0*	6.8	13.3*	5.6
—	—	21.*	0.1	—	—	—	—	22.3	—	—	—
—	—	—	—	**15.9**	—	**14.6**	11.9	—	—	—	—
—	—	—	—	30.	3.1	—	—	—	—	—	—
—	—	—	—	41.2	0.22	—	—	—	—	—	—

(* Probably due to pendulum oscillations).

In the above table the periods given in fat letters are those meaned from the values for the two or all of the three different stations. The average values of these periods are as follows:—

4.96 sec.; (max. $2a=0.33^{\rm mm.}$, in 2nd prel. trem., and 3rd phase of princ. port.)

9.70 „ ; (max. $2a=12.8^{\rm mm.}$, 3rd ph. of princ. portion).

15.3 „ ; („ $=11.9^{\rm mm.}$, „ „ .)

Thus the period of 4.96 sec. occurred throughout the different portions of the earthquake motion, the period of 9.7 sec. occurring in the principal and end portions. The longest periods of 30 and 41.2 sec. occurred in the 1st and 2nd phases of the principal portion. The vibrations of average periods of 9.7 and

15.3 sec. had the greatest $2a$'s respectively of 12.8 and 11.9 mm, while those with the periods of 4.96 sec. had a much smaller $2a$ of 0.33 mm. The vibrations of the macroseismic nature, or those of $T=1.07$, 2.1, and 3.3 sec., were very small.

The values of the different periods meaned from all the phases of the earthquake motion are given in the following table; the corresponding $2a$'s being the maximum ranges among the three stations.

$T=1.07$ sec.,	$2a=$ — mm.
2.1	—
3.3	—
4.96	0.33
6.3	0.50
9.7	12.8
12.4	13.8
15.3	11.9
21.7	0.1
30.0	3.1
41.2	0.22

That vibrations of poriods respectively equal to the two last of the above series have been registered by the short-period horizontal pendulums indicates the existence of slow movements with large amplitude.

126. ***Note on the Horizontal Pendulum Observations of Earthquakes at Taichu, in 1903 and 1904.*** For the sake of reference, I give here a few remarks on the period of vibration at Taichu based on the examination of the eastwest diagrams of 12 earthquakes observed at the latter place between Jan. 1903 and Sept. 1904. Each of these earthquakes was of a comparatively near origin, and the duration of the total preliminary tremor varied between 11 and and 31 sec.; the total earthquake duration varying from 7½ to 22 min.

The average complete periods in the different phases of the earthquake motion were as follows:—

Preliminary Tremor.	*Principal Portion.*	*End Portion.*
sec. 0.69	sec. 3.4	sec. 3.3
4.6	**4.97**	**4.95**
8.0	7.6	
	10.3	

Thus the period of vibration most frequently happening throughout the three principal divisions of the earthquake motion varied between 4.6 and 4.97 sec., the general mean value being 4.9 sec. This is evidently identical with the period P_1, found from the seismograms obtained in Tokyo; the value of P_1 meaned from the observations at Hongō and Hitotsubashi (both in Tokyo) being 4.6 sec. Further, the period P_1 is identical with the period Q_1, of the "pulsatory oscillations," at Tokyo, whose mean value was found to be 4.4 sec. (See the "Publications of the Earthq. Inv. Comm.," Nos. 5 and 13.) Hereby it is interesting to note that the horizontal pendulum diagrams obtained at the town of Taitō, which is on the eastern coast of Formosa, indicates pulsatory oscillations of an average period of about 5.0 sec.

The horizontal pendulum employed at Taichu was unable, on account of the shortness of its period of free oscillation (=15sec.), to satisfactorily register vibrations of much longer period. On this very account, however, I was enabled to recognize the existence in the *principal portion* of vibrations of P_1 period. That the long-period horizontal pendulums at Tokyo did not usually show, in cases of large earthquakes, vibrations of P_1 or P_2 period in the principal portion, is probably due to the predominance of the record of slow period movements, the short period ones being thereby obscured.

127. ***Ōsaka.*** Table XXV gives the periods occurring in the different phases of earthquake motion at Ōsaka (§ 22).

TABLE XXV. Periods of Vibration at Ōsaka.

		sec.	sec.	sec.	sec.	sec.	sec.	sec.	sec.	sec.
	1st Prel. Trem.	4.6	7.8	—	—	—	—	23.8	—	
	2nd. Prel. Trem.	—	—	—	—	—	20.2	25.5	32.5 30.0	
Princ. Port.	1st, 2nd Ph.	—	—	—	—	—	21.7	—	—	28.3*
	3rd Phase.	—	—	11.3	—	—	—	24.2	—	26.8*
	4th „	—	—	10.5	—	—	22.2	—	—	
	5th „	—	—	10.2	14.4	18.5	—	—	—	
	End Portion.	—	—	10.8	14.2	—	21.7	—	—	
	W_2	—	—	—	—	18.5	20.4	25.1	—	
	W_3	—	—	—	—	18.5	—	—	—	
	Mean	**4.6**	**7.8**	**10.7**	**14.3**	**18.5**	**21.2**	**24.7**	32.5 30.0	27.6

(*Proper pendulum oscillations).

The periods of vibration in the W_3 motion was 18.5 sec., being equal to that of the most active part in W_2.

From Table XXV, it will be seen that the periods of average values of 21.2 and 24.7 sec. occurred in the different phases of the earthquake motion as well as in the W_2 wave, or the movement propagated along the major arc. Again, all the different periods occurring at Ōsaka can be identified in the seismograms obtained at the stations considered in the preceding §§.

128. ***Comparison of the NS Component Records at Tokyo and Kobe.*** The following table gives a comparison of the elements of motion in the NS component recorded at Tokyo and Kobe, based on the analyses given in §§ 15 and 23.

TABLE XXVI. Periods of Vibration in the NS Component at Tokyo and Kobe. (*....Pendulum Oscillation.)

Tokyo.		Kobe.	
[1st Preliminary Tremor.]			
Duration $= 7^{\text{m}}\ 6^{\text{s}}$		Duration $= 7^{\text{m}}\ 0^{\text{s}}$	
$T = 5.2^{\text{sec.}}$	$2a = 0.14^{\text{mm}}$	$T = 4.4^{\text{sec.}}$	$2a = 0.05^{\text{mm}}$
—	—	11.5	—
15.8	0.22	—	—
20.0	0.43	—	—
—	—	—	—
29.8	0.43	—	—
[2nd Preliminary Tremor.]			
Duration $= 8^{\text{m}}\ 20^{\text{s}}$		Duration $= 5^{\text{m}}\ 44^{\text{s}}$(?)	
$T = —$	$2a = —$	$T = —$	$2a = —$
—	—	$30.0^{\text{sec.}}$*	3.0^{mm}
$33.5^{\text{sec.}}$	1.63^{mm}	—	—
40.4	3.53	—	—
45.0*	3.95	—	—
55.2	—	—	—
[Principal Portion.]			
$10.7^{\text{sec.}}$	1.7^{mm}	$10.7^{\text{sec.}}$	0.19^{mm}
19.5	1.3	18.2	2.0
22.8	0.58	23.5	1.1
—	—	28.3*	8.2

Tokyo.		Kobe.	
—$^{\text{sec.}}$	—$^{\text{mm}}$	33.0$^{\text{sec.}}$	2.7$^{\text{mm}}$
—	—	40.3	4.8
44.3*	8.3	—	—
—	—	55.8	2.0

[End Portion.]

12.9$^{\text{sec.}}$	0.3$^{\text{mm}}$	13.1$^{\text{sec.}}$	—$^{\text{mm}}$
26.2	—	—	—

[W_2 Motion.]

12.3$^{\text{sec.}}$	—$^{\text{mm}}$	—	—
18.8	0.12	—	—
25.8	0.10	—	—
29.5	—	—	—
45.0*	0.10	—	—

The following table has been formed from a comparison of the periods at the two stations as given in the preceding one.

TABLE XXVII. Mean Periods occurring at Tokyo and Kobe. NS Component.

1st preliminary Tremor.		2nd Preliminary Tremor.		Principal Portion.		End Portion.		W_2	
T	$2a$	T	$2a$	T	$2a$	T	$2a$	T	$2a$
sec.	mm	sec.	mm	sec.	mm	sec.	mm	sec.	mm
4.8	0.14	—	—	—	—	—	—	—	—
11.5	—	—	—	**10.7**	1.7	—	—	—	—

1st Preliminary Tremor.		2nd Preliminary Tremor		Principal Portion.		End Portion.		W_2	
T sec.	$2a$ mm	T sec.	$2a$ mm	T sec.	$2a$ mm	T sec.	$2a$ mm	T sec.	$2a$ mm
—	—	—	—	—	—	**13.0**	0.3	12.3	—
15.8	0.22	14.8	—	—	—	—	—	—	—
20.0	0.43	—	—	**18.9**	2.0	—	—	**18.3**	0.12
—	—	—	—	**23.2**	1.1	—	—	—	—
—	—	—	—	—	—	26.2	—	25.8	0.10
29.8	0.43	**30.3***	3.0	**28.3**	8.2	—	—	29.5	—
—	—	**33.5**	1.63	33.0	2.7	—	—	—	—
—	—	40.4	3.53	**40.3**	4.8	—	—	—	—
—	—	45.0*	3.95	44.3*	8.3	—	—	45.0*	0.10
—	—	55.2	—	55.8	2.0	—	—	—	—

In the above table, the amplitude corresponding to any given period is the maximum among those for the two places.

The values of the different periods meaned through all the different portions of the earthquake motion, and the corresponding maximum $2a$'s, are given in the following table; the values of the periods evidently due to the pendulum oscillations being excluded.

$T=$ **4.8** sec.,	$2a=0.14$ mm
11.1	1.7
12.7	0.3
15.3	0.22
19.2	2.0
24.6	1.1
29.4	0.43
33.3	2.7
40.2	4.8
55.5	2.0

Many of these periods will be found to exist also in the Ōsaka and Formosa EW records, as well as in the Birmingham and Quarto-Castello seismograms. It is to be specially noted that the two last in the above series, namely, the long periods of 40.2 and 55.5 sec. occurred respectively in the Formosa and Quarto-Castello records.

129. ***American and Mexican Stations.*** Tables XXVIII and XXIX give respectively the periods and the corresponding max. movements at the American and Mexican stations.

TABLE XXVIII. Periods and Range of Vibration.
EW Component.

Phase of motion.	Cheltenham.		Tacubaya.		Mean.	
	T sec.	2*a* mm	*T* sec.	2*a* mm	*T* sec.	2*a* mm
1st Prel. Tremor.	7.8	(small)	7.7	—	7.8	—
	12.3	0.05	14.2	—	13.3	0.05
2nd Prel. Tremor.	—	—	11.7	(small)	11.7	—
	14.4	0.05	—	—	14.4	0.05
	—	—	32.2	0.10	32.2	0.10
	41.0	0.10	—	—	41.0	0.10
1st and 2nd Phases, Principal Portion.	64.0	0.12	—	—	64.0	0.12
	54.0	0.12	57.4	0.10	55.7	0.12
	45.5	0.12	45.8	0.10	45.7	0.12
	—	—	37.5	0.12	37.5	0.12
	30.0	0.08	—	—	30.0	0.08
	22.4	0.12	24.8	(small)	23.6	0.12
	15.2	(small)	—	—	15.2	—

Phase of motion.	Cheltenham.		Tacubaya.		Mean	
	T	$2a$	T	$2a$	T	$2a$
	sec.	mm	sec.	mm	sec.	mm
3rd Phase,	19.7 *	0.83	18.1 *	0.15	—	—
Principal Portion.	—	—	22.5	0.12	22.5	0.12
4th, etc., Phases,	15.6	0.21	17.5 *	—	15.6	0.21
Principal Portion.	20.2 *	0.36	21.2	—	—	—
W_2	18.6 *	0.28	18.0 *	0.10	—	—

TABLE XXIX. Periods and Range of Vibration. NS Component.

Phase of motion.	Cheltenham.		Washington.		Tacubaya.		Mean.	
	T	$2a$	T	$2a$	T	$2a$	T	$2a$
	sec.	mm.	sec.	mm.	sec.	mm.	sec.	mm.
1st Prel. Tremor.	—	—	4.3	—	—	—	4.3	—
	7.1	—	6.3	—	8.9	—	7.4	—
	12.6	—	—	—	—	—	12.6	—
	30.3	—	—	—	—	—	30.3	—
	40.7	0.15	—	—	—	—	40.7	0.15
2nd Prel. Tremor.	8.4	—	—	—			8.4	—
	11.2	—	—	—			11.2	—
	—	—	21.4	—			21.4	—
	24.6	0.06	—	—			24.6	0.06
	30.7	0.09	28.0	—			29.4	0.09
	—	—	39.5	—			39.5	—
	46.0	0.07	—	—			46.0	0.07

* Pendulum oscillations.

Phase of motion.	Cheltenham.		Washington.		Tacubaya.		Mean.	
	T	2*a*	*T*	2*a*	*T*	2*a*	*T*	2*a*
	sec.	mm	sec.	mm	sec.	mm	sec.	mm
1st and 2nd Phases, Princ. Portion.	62.3	0.14	—	—	—	—	62.3	0.14
	48.0	0.09	49.5	0.05	—	—	48.8	0.09
	—	—	44.3	—	45.0	0.10	44.7	0.10
	—	—	—	—	40.3	0.10	40.3	0.10
	29.8	0.24	—	—	—	—	29.8	0.24
	—	—	27.8	0.08	—	—	27.8	0.08
	25.8	—	—	—	—	—	25.8	—
	14.1	—	—	—	—	—	14.1	—
3rd Phase, Princ. Portion.	17.5*	2.12	15.1	—	15.8*	0.30	15.1	—
	21.2	—	19.4*	1.2	—	—	21.2	—
	—		—		24.0	0.12	24.0	0.12
4th Phase., Princ. Portion., and End Portion.	16.1*	0.21	—	—	16.3*	—	16.2*	0.21
	21.6	0.05	—	—	—	—	21.6	0.05
W_2	29.0	0.06	27.0	—	—	—	28.0	0.06
	22.8	0.19	21.9	—	—	—	22.4	0.19
	18.5	0.06	—	—	19.4	0.48	19.0	0.48
	—	—	16.5	—	16.0*	0.15	16.3*	0.15
	—	—	13.5	—	—	—	13.5	—

The NS and EW components correspond, in the cases of the American and Mexican stations, approximately to the longitudinal and transverse waves, and, as will be seen from Tables XXVIII and XXIX, the vibrations in the principal portion and W_2 motion was markedly greater in the NS component. Similar periods, however, seem to occur in the two horizontal components, the notable examples being slow periods of 40 to over 60 seconds.

The mean periods of vibration deduced from the EW and NS component observations at the three stations in question are given in Table XXX; the $2a$'s being each the corresponding maximum range among the different components.

TABLE XXX. Periods and Range of Vibration. EW and NS.
Cheltenham, Washington, Tacubaya.

Phase of motion.	T	$2a$.	Phase of motion.	T	$2a$.
	sec.	mm		sec.	mm
1st Preliminary Tremor.	4.3	—	3rd Phase, Principal Portion.	15.1	—
	7.6	—		**21.9**	0.12
	13.0	0.05		24.0	0.12
	30.3	--			
	40.7	0.15	4th, etc. Ph., P.P. End portion.	15.6	0.21
				16.2 *	0.21
2nd Preliminary Tremor.	8.4	—		21.6	0.05
	11.5	—			
	14.4	0.05			
	21.4	—	W_2	28.0	0.06
	24.6	0.06		22.4	0.19
	29.4	0.09		19.0	0.48
	32.2	0.10		16.3 *	0.15
	40.3	0.10		13.5	—
	46.0	0.07			
1st and 2nd Phases, Principal Portion.	**63.2**	0.14			
	55.7	0.12			
	48.8	0.09			
	45.2	0.12			
	40.3	0.10			
	37.5	0.12			
	29.9	0.24			
	27.8	0.08			
	24.7	0.12			
	14.7	—			

Finally taking the averages of the different periods from the successive phases of motion, we obtain :—

$T =$ 4.3 sec.	$2a =$ — mm
7.9	—
11.5	—
14.3	0.05
21.2	0.48
24.1	0.19
31.1	0.24
37.5	0.12
40.4	0.15
46.3	0.12
55.7	0.12
63.2	0.14

Thus, in this case we have a long period of 63.2 sec., all the other periods, ranging from 4.3 sec. up to 55.7 sec., being also found at some or other of the stations considered in the preceding §§.

130. ***Periods of Vibration at the different Places.*** From the foregoing §§ it will be seen that many periods of vibration were common to several of the stations. To compare generally the periods occurring at different places, I give, in the four tables, XXXI to XXXIV, the period (T) and the corresponding range ($2a$) in the different phases of the earthquake motion observed at 10 stations, as follows :—

Table XXXI ....Tokyo.
„ XXXII ....Ōsaka, Kōbe, Tadotsu.
„ XXXIII....Birmingham, Quarto-Castello.
„ XXXIV ....Potsdam, Leipzig, Göttingen, Upsala.

Besides these, Tables XXIV and XXX, already given, contain the elements of motion in question, respectively for Taihoku, Taichu, and Tainan, and for Cheltenham, Washington, and Tacubaya. The observation of the periods at the above named 16 places are more .complete than that at the others.

(*....pendulum motion.)

TABLE XXXI. Periods of Vibration and Max. $2a$. ***Tokyo.***

Phase of motion	E W § 14.		E W Tromometer. § 20.		E W Tromometer. Centr. M. O.		N S.		Vertical.		**Mean.**	
	T	$2a$	T	$2a$	T	$2a$	T	$2a$	T	$2a$	T	$2a$
	sec.	mm.	sec.	mm.	sec.	mm.	sec.	mm.	sec.	mm.	sec.	mm.
1st Preliminary Tremor.	4.6	0.20	4.4	0.25	4.4	0.17	5.2	0.14	4.2	—	4.5	0.25
	8.0	0.30	8.6	0.33	7.4	0.22	—		7.3	0.31	7.8	0.33
	—		—		—		15.8	0.22	—		15.8	0.22
	—		—		—		20.0	0.43	—		20.0	0.43
	24.7	0.57	—		—		—		—		24.7	0.57
	—		—		—		29.8	0.43	—		29.8	0.43
2nd Preliminary Tremor.	—		4.8	0.21	—		—		—		4.8	0.21
	9.0	Small	8.8	0.61	9.1	1.06	—		—		9.0	1.06
	—		11.8	1.05	—		—		—		11.8	1.05
	—		—		—		23.1	2.33	—		23.1	2.33
	26.5	0.97	—		—		—		—		26.5	0.97
	—		—		—		33.5	1.63	—		33.5	1.63
	37.1	4.50	—		—		—		—		37.1	4.50
	—		—		—		40.4	3.53	—		40.4	3.53
	—		—		—		45.3	3.95	—		45.3	3.95
	49.7	5.80	—		—		—		—		49.7	5.80
	54.0	—	—		—		55.2	—	—		54.6	—
	86.0	2.27	—		—		—		—		86.0	2.27

TABLE XXXI. *Cont.*

Phase of motion	E W § 14.		E W Tromometer. § 20.		E W Tromometer. Centr. M. O.		N S.		Vertical.		**Mean.**	
	T	2*a*	*T*	2*a*	*T*	2*a*	*T*	2*a*	*T*	2*a*	*T*	2*a*
	sec.	mm.	sec.	mm.	sec.	mm.	sec.	mm.	sec.	mm.	sec.	mm.
1st and 2nd Phases, Principal Portion.	—		9.3	0.40	8.1	0.23	—		—		8.7	0.40
	11.3	0.33	—		—		—		—		11.3	0.33
	—		16.8	0.53	—		—		—		16.8	0.53
	—		—		—		—		22.3	0.13	22.3	0.13
	27.6	6.24	29.0	0.66	—		—		29.7	0.28	28.8	6.24
	—		38.5	0.58	36.8	0.20	—		—		37.7	0.58
	—		—		—		42.5	—	—		42.5	—
	—		—		—		47.8	6.65	45.2	0.07	46.5	6.65
	53.0	10.8	53.0	0.36	—		—		—		53.0	10.80
	59.0	1.30	—		—		—		—		59.0	1.30
3rd Phase, Princ. Portion.	10.8	3.67	—		10.0	2.90	10.3	1.70	—		10.4	3.67
	16.8	2.40	—		—		—		14.1	0.29	15.5	2.40
	20.5	—	21.0	*	23.8	—	23.0	—	—		22.1	—
	—		34.8	Large	—		—		—		34.8	Large
	—		—		—		42.5	2.70	—		42.5	2.70
4th etc. Phases, Princ. Portion; End Portion.	—		8.2	0.24	—		—		—		8.2	0.24
	11.3	0.80	—		11.1	2.20	10.8	1.40	11.6	—	11.2	2.20
	13.2	0.72	12.1	1.67	—		12.8	0.30	—		12.7	1.67
	—		—		15.2	0.78	—		15.7	—	15.5	0.78
	—		—		—		—		19.5	1.30	—		19.5	1.30
	—		—		—		22.6	0.58	—		22.6	0.58
	—		—		—		26.2	—	—		26.2	—

TABLE XXXII. Periods and Max.$2a$. ***Ōsaka, Kōbe, Tadotsu.***

Phase of motion.	Ōsaka (EW)		Kōbe (NS)		Tadotsu (EW)		**Mean.**	
	T	$2a$	T	$2a$	T	$2a$	T	$2a$
	sec.	mm	sec.	mm	sec.	mm	sec.	mm
1st Preliminary Tremor.	4.6	0.53	4.4	0.05	4.7	—	4.6	0.53
	7.8	Small	——		——		7.8	—
	——		11.5	—	10.4	—	11.0	—
	23.8	1.05	——		24.4*	0.20	24.0	1.05
2nd Preliminary Tremor.	——		——		14.8	—	14.8	—
	20.2	1.58	——		——		20.2	1.58
	25.5	1.69	——		——		25.5	1.69
	30.0 32.5	— 2.53	30.0*	3.0	31.5	0.86	30.9	3.00
	——		——		36.5	0.14	36.5	0.14
1st and 2nd Ph., Princ. Portion.	21.7	1.58	——		19.0	—	20.4	—
	28.3*	4.5	——		——		28.3	4.50
	——		34.0	0.48	——		34.0	0.48
	——		40.3	4.8	39.4	1.4	39.9	4.80
	——		55.8	2.0	——		55.8	2.00
3rd Phase, Princ. Portion.	11.3	—	——		——		11.3	—
	——		18.5	2.00	——		18.5	2.00
	24.2	2.25	——		——		24.2	2.25
	26.8*	11.7	28.3	8.20	28.0*	Large.	27.7	11.70
	——		32.0	2.70	——		32.0	2.70
4th, etc. Phases, Princ. Portion; End Portion.	10.5	0.14	10.7	0.19	10.2	0.53	10.5	0.53
	14.3	0.63	13.1	—	13.6	0.27	13.7	0.63
	18.5	0.68	17.8	0.45	19.7	0.72	18.7	0.72
	22.0	1.73	23.5	1.10	——		22.8	1.73

TABLE XXXIII. Periods of Vibration and Max. $2a$.

Birmingham and Quarto-Castello.

Phase of motion.	Birmingham. (EW)		Quarto-Castello. (EW and NS)		**Mean.**	
	T	$2a$	T	$2a$	T	$2a$
	sec.	mm	sec.	mm	sec.	mm
1st Preliminary Tremor.	**4.6**	—	**4.3**	0.04	4.5	0.04
	7.1	—	6.4	0.02	6.8	0.02
	——		9.1	0.07	9.1	0.07
	12.0	0.035	——		12.0	0.035
2nd Preliminary Tremor.	4.6	—	**4.8**	0.04	4.7	0.04
	9.7	0.028	**8.6**	0.26	9.2	0.26
	——		11.1	0.25	11.1	0.25
	15.5	0.083	——		15.5	0.083
	——		54.5	0.51	54.5	0.51
1st and 2nd Phases, Principal Portion.	——		4.9	—	4.9	—
	7.5	—	——		7.5	—
	9.9	0.07	**9.1**	0.30	9.5	0.30
	18.8	0.16	——		18.8	0.16
	——		29.8	0.44	29.8	0.44
	36.6	0.24	——		36.6	0.24
	——		50.0	0.22	50.0	0.22
3rd Phase, Principal Portion.	——		6.9	0.034	6.9	0.034
	——		**10.0**	0.44	10.0	0.44
	17.9	1.56	**15.0**	0.63	16.5	1.56
	——		26.6	0.72	26.6	0.72
	31.4	2.03	——		31.4	2.03

Phase of motion.	Birmingham. (EW)		Quarto-Castello. (EW and NS)		**Mean.**	
4th, etc. Phases, Principal Portion; End Portion.	—		**4.9**	—	4.9	—
	10.1	0.04	9.1	0.38	9.6	0.38
	12.3	0.60	12.1	0.46	12.2	0.60
	14.5	0.25	**14.5**	0.57	14.5	0.57
	16.7	—	**16.7**	0.22	16.7	0.22
	—		**18.8** *	0.48	18.8*	0.48

TABLE XXXIV. Periods of Vibration and Max. $2a$.

Potsdam, Leipzig, Göttingen, Upsala.

Phase of motion.	Potsdam.		Leipzig.	Göttingen.	Upsala.	**Mean.**
	T	*2a*	*T*	*T*	*T*	*T*
	sec.	mm	sec.	sec.	sec.	sec.
1st Preliminary Tremor.	5.4	0.12	4.3	4.4	**4.4**	4.6
	—		7.9	**8.8**	**8.5**	8.4
	—		10.7	11.7	—	11.2
	—		—	17.3*	—	17.3*
2nd Preliminary Tremor.	**4.6**	0.24	4.5	—	**5.5**	4.9
	—		**9.6**	10.2	**7.9** 10.1	9.7
	—		13.6	13.4	**12.8**	13.4
	—		16.2	—	14.5	15.4
	21.3	0.37	—	—	—	21.3
	26.9	0.34	—	—	—	26.9
	—		38.0	—	—	38.0
	—		47.5	—	—	47.5

Phase of motion.	Potsdam.		Leipzig.	Göttingen.	Upsala.	**Mean.**
	T	2*a*	*T*	*T*	*T*	*T*
	sec.	mm	sec.	sec.	sec.	sec.
1st and 2nd Ph., Princ. Portion.	4.0	—	—	—	—	4.0
	7.7	0.33	**9.3**	—	8.4	8.5
	——		—	—	15.9	15.9
	30.5	0.33	**29.7**	30.6	—	30.3
	——		**36.8**	36.0	—	36.4
	43.3	0.47	—	—	—	43.3
	——		49.2	48.3	—	48.8
	55.2	1.55	—	—	—	55.2
3rd, etc. Ph., Princ. Portion.	——		**9.0**	**9.4**	**9.3**	9.2
	——		12.0	11.0	13.4	12.1
	16.2*	2.50	—	15.0*	—	15.6*
	19.6	1.00	20.9	—	—	20.3
	24.1	—	24.3	—	—	24.2
	29.5	1.28	—	—	—	29.5
End Portion.	——		**10.2**	—	**9.2**	9.7
	——		—	—	**11.9**	11.9
	——		—	17.6*	**14.3**	14.3 17.6*
	——		**22.4**	—	**21.9**	22.2
	——		—	—	26.6	26.6

A glance on Tables XXIV, XXX, XXXI, XXXII, XXXIII, and XXXIV, will show that several periods existed simultaneously at the different stations. To show this relation more clearly, I have collected in the following table the mean values of the different periods and the corresponding max. 2*a*'s occurring in the successive phases of the earthquake motion for the 16 stations considered before; similar periods being placed on the same horizontal rows.†

TABLE XXXV. Kangra Earthquake. Periods of Vibration and Max. $2a$ at the different Stations. [GENERAL SUMMARY.]

(*....Pendulum Oscillations.)

Phase of motion.	Tokyo.		Ōsaka; Kōbe; Tadotsu.		Taihoku; Taichu; Tainan.		Birm'gham; Quarto-Castello.		Potsdam; Leipzig; Göttingen; Upsala.	Chelt'ham; Wash'gton; Tacubaya.		**Mean Periods.**
	T	$2a$	*T*	$2a$	*T*	$2a$	*T*	$2a$	*T*	*T*	$2a$	*T*
	sec.	mm	sec.	mm	sec.	mm	sec.	mm	sec.	sec.	mm	sec.
1st Preliminary Tremor.	4.5	0.25	4.6	0.53	4.3	0.17	4.5	0.04	4.6	4.3	—	**4.5**
	7.8	0.33	7.8	—	5.8	—	6.8 9.1	0.02 0.07	8.4	7.6	—	**8.1** 6.3
	——		11.0	—	——		12.0	0.04	11.2	——		11.4
	15.8	0.22	——		13.8	0.08	——		—	13.0	0.05	14.2
	20.0	0.43	——		——		——		17.3*	——		20.0 17.3*
	24.7	0.57	24.0	1.05	——		——		—	——		24.4
	29.8	0.43	——		——		——		—	30.3	—	30.1
	——		——		——		——		—	40.7	0.15	40.7
2nd Preliminary Tremor.	4.8	0.21	——		4.7	0.33	4.7	0.04	4.9	——		**4.8**
	9.0	1.06	——		——		9.2	0.26	9.7	8.4	—	**9.1**
	11.8	1.05	——		11.2	2.30	11.1	0.25	13.4	11.5	—	**11.4** 13.4
	——		14.8	—	——		15.5	0.08	15.4	14.4	0.05	**15.0**
	23.1	2.33	20.2	1.58	21.0	0.10	——		21.3	21.4	—	**21.0** 23.1
	26.5	0.97	25.5	1.69	——		——		26.9	24.6	0.06	**25.9**
	——		30.9	3.00	——		——		—	29.4	0.09	30.2
	33.5	1.63	——		——		——		—	32.2	0.10	32.9
	37.1	4.50	36.5	0.14	——		——		38.0	——		**37.2**
	40.4	3.53	——		——		——		—	40.3	0.10	40.4
	45.3	3.95	——		——		——		47.5	46.0	0.07	**46.3**
	49.7	5.80	——		——		——		—	——		49.7
	54.6	—	——		——		54.5	—	—	——		54.6
	86.0	2.27	——		——		——		—	——		86.0

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† The $2a$ in Table XXXV is the greatest value, among the different stations, of the range of motion in EW or NS component, corresponding to a given period.

TABLE XXXV. *Cont.*

Phase of motion.	Tokyo.		Osaka; Kobe; Tadotsu.		Taihoku; Taichu; Tainan.		Birm'gham; Quarto-Castello.		Potsdam; Leipzig; Göttingen; Upsala.	Chelt'ham; Wash'gton; Tacubaya.		**Mean Periods.**
	T	2*a*	*T*	2*a*	*T*	2*a*	*T*	2*a*	*T*	*T*	2*a*	*T*
	sec.	mm	sec.	mm	sec.	mm	sec.	mm	sec.	sec.	mm	sec.
1st and 2nd Phases, Principal Portion.	—		—		4.5	0.23	4.9	—	4 0	—		**4.5**
	8.7	0.40	—		6.8	0.50	7.5	—	8.5	—		**7.9**
	11.3	0.33	—		10.0	2.00	9.5	0.30	—	—		**10.3**
	16.8	0.53	—		15.9	—	—		15.9	14.7	—	**15.8**
	22.3	0.13	20.4	—	—		18.8	0.16	—	—		**20.5**
	—		—		—		—		—	24.7	0.12	24.7
	28.8	6.24	28.3	4.50	30.0	3.10	29.8	0.44	30.3	29.9	0.24	**29.5**
	37.7	0.58	34.0	0.48	—		36.6	0.24	36.4	37.5	0.12	**36.4**
	42.5	—	39.9	4.80	41.2	0.22	—		—	40.3	0.10	**41.0**
	46.5	6.65	—		—		—		43.3	45.2	0.12	**45.0**
	—		—		—		50.0	0.22	48.8	48.8	0.09	**49.2**
	53.0	10.80	55.8	2.00	—		—		55.2	55.7	0.12	**54.9**
	59.0	1.30	—		—		—		—	—		59.0
	—		—		—		—		—	63.2	0.14	63.2
3rd Phase, Principal Portion.	—		—		5.4	0.33	6.9	0.03	—	—		6.2
	10.4	3.67	11.3	—	9.9	12.80	10.0	0.44	9.2 12.1	—		**10.2** 12.1
	15.5	2.40	18.5	2.00	14.6	11.90	16.5	1.56	15.6*	15.1	—	**15.5** 18.5
	22.1	—	—		—		—		20.3	21.9	0.12	**21.4**
	—		24.2 27.7	2.25 11.70	—		26.6	0.72	24.2	24.0	0.12	**24.8** 27.7
	—		32.0	2.70	—		31.4	2.30	29.5	—		**31.0**
	34.8	Large	—		—		—		—	—		34.8
	42.5	2.70	—		—		—		—	—		42.5
4th, etc. Ph., Principal Portion.; End Portion.	—		—		5.9	0.17	4.9	—	—	—		5.4
	8.2	0.24	10.5	0.53	8.4	1.20	9.6	0.38	9.7	—		**9.3**
	11.2	2.20	—		10.3	0.50	—		11.9	—		**11.1**
	12 7	1.67	—		12.7*	6.80	12.2	0.60	—	—		**12.5**
	15.5	0.78	13.7	0.63	—		14.5 16.7	0.57 0.22	14.3	15.6	0.21	**14.7** 16.7
	19.5	1.30	18.7	0.72	—		18.8	0.48	17.6*	—		**18.7**
	22.6	0.58	22.8	1.73	22.3	—	—		22.2	21.6	0.05	**22.3**
	26.2	—	—		—		—		26.6	—		26.4

The values of the different periods occurring in the Kangra earthquake (Table XXXV), obtained by taking the averages from the various phases of the earthquake motion are indicated in Table XXXVI. For the sake of comparison, I have also given in the same table the periods which were found for the following three sets of great teleseismic disturbances:—

(i) Tokyo Horizontal Components Observation of the Caracas earthquake of Oct. 29, 1900, and the Guatemala earthquake of April 19, 1902.

(ii) Tokyo, Ōsaka, and Manila Observations of the Valparaiso earthquake of Aug. 17, 1906. Horizontal and Vertical Components.

(iii) E W Component Observations in Tokyo of the 10 earthquakes, namely, 3 Alaska eqkes of Sept. 4 and 10, 1899, and Oct. 9, 1900; 2 Mexico eqkes of Jan. 20, 1900, and Sept. 22, 1902; Guatemala eqke of April 19, 1902; Caracas eqke of Oct. 29, 1900; Aidin eqke of Sept. 20, 1899; Kashgar eqke of Aug. 22, 1902; and Sumatra eqke of Jan. 5, 1900.

These 10 earthquakes, together with the Guam Island eqke of Sept. 22, 1902, compose the 11 disturbances referred to in § 8. The two earthquakes of Group (i) are included in Group (iii).

TABLE XXXVI. Periods of Vibration in Kangra, Valparaiso, and other Earthquakes.

i	ii	iii	iv	Mean Values of Periods, deduced from (ii), (iii), (iv).	
Caracas and Guatemala Earthquakes (Tokyo, Horiz.)	Valparaiso Earthquake (Tokyo, Ōsaka, Manila).	10 Large Eqkes observed in Tokyo (EW Component).	Indian Eqke* (16 Stations).		
sec.	sec.	sec,	sec.	sec.	
—	—	1.5	—		
2.9	—	—	—		
—	4.0	4.1	**4.7**	**4.3**......	P_1
7.9	8.4	**8.9**	**8.6**	**8.6**	P_2
10.2	11.4	—	**11.2**	**11.3**	$P_{2,3}$
14.8	15.1	**14.5**	**15.1**	**14.9**	P_3
18.4	18.3	—	—	**18.3**	P_4
—	—	**20.0**	**20.7**	**20.4**	P_5
21.2	22.6	—	—	**22.6**	$P_{5,6}$
26.9	26.8	24.6	**25.6**	**25.7**	P_6
—	28.7	28.3	—	**2.58**	P_7
—	—	—	**30.1**	**30.1**	$P_{7,8}$
32.9	32.4	—	—	**32.4**	P_8
—	37.1	**34.4**	**36.4**	**35.9**	P_9
39.5	—	42.9	**41.1**	**42.0**	P_{10}
45.4	45.0	—	45.7	**45.4**	P_{11}
—	—	—	49.4	**49.4**	P_{12}
56.0	—	54.0	54.8	**54.4**	P_{13}
—	—	—	59.0	**59.0**	P_{14}
—	67.4	66.0	63.0	**65.5**	P_{15}
			⋮	⋮	⋮
—	—	—	86.0	**86.0**	P_{19}

(*The quick vibrations which occurred in some of the diagrams of the Kangra earthquake are noted in a subsequent §.)

From Table XXXVI, it will be seen that many periods of vibration are common to the four groups (i) to (iv). Especially the periods in the Caracas and Guatemala earthquakes observed in Tokyo were very nearly alike to those in the Valparaiso earthquake observed in Tokyo, Ōsaka, and Manila; while the periods occurring in the Kangra earthquake were similar to those found in the cases of the 10 earthquakes of group (iii). We are, therefore, justified in deducing the average values of the various periods from observations of the different earthquakes. The results thus obtained from (ii), (iii), and (iv),* are denoted in the table by the symbols P_1, $P_2 \ldots\ldots P_{15} \ldots\ldots P_{19}$. Of these, the periods (P_1 to P_{11}) and P_{13} correspond respectively to the successive periods represented by the same letters in § 8. The periods P_{12}, P_{14}, P_{15}, and P_{19} form additions to the series before obtained.

As stated in my previous papers,† we have the following approximate relations :—

$$P_1 = \frac{P_2}{2} = \frac{P_3}{3} = \frac{P_4}{4} = \ldots\ldots \frac{P_{10}}{10} = \ldots\ldots \frac{P_n}{n},$$

where n denotes an integer, whose maximum limit is provisionally 19. According to the above assumption, P_1 is to be regarded as the fundamental or unit period of the micro-seismic movements, the different longer periods being its multiples. The most probable value of P_1 may be found as follows :—

$$P_1 = \sum_1^{15} P_n \Big/ \sum_1^{15} n = 4.2 \text{ sec.},$$

$P_{19} = 86$ sec. being, for the present calculation, left out of account, as it depends on a single observation. (Compare the *Publications*, No. 21, p.p. 83–84.)

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* (i) is included in (iii).

† The *Publications*, No. 21.

The conclusion to be drawn, with respect to the vibration periods, from what has been said above is as follows:—The teleseismic motion is essentially the same in character at different places all over the world, and consists of a set of vibrations, whose periods are approximately equal to P_1, P_2, P_3....... These latter may be considered as the seismic constants, not of a particular district, but of the whole earth's crust. Short period vibrations, which constitute the macro-seismic or sensible earthquake motion, are of short wave length and much depend on the nature of the ground of the observing place.

The discussions in these §§ are to be regarded only as provisionary; the division of the periods of vibration into the different groups, P_1, P_2, P_3,...... being sometimes more or less arbitrary. Besides the 16 mean periods considered above there are two frequently occurring intermediate ones, respectively equal to 11.3 and 22.6 sec., and denoted in Table XXXVI by $P_{2,3}$ and $P_{5,6}$. The lengths of these two periods are in the ratio of 1 : 2. In the Kangra earthquake there was also a third intermediate period of $P_{7,8}=30.1$ sec.

131. ***Periods of Micro-seismic Vibrations in the different Phases.*** According to Table XXXV, the periods of the micro-seismic vibrations occurring in the successive phases of the Kangra earthquake were as follows, those more frequently occurring being, as usual, printed in fat characters:—

TABLE XXXVII. Kangra Earthquake. Periods of Vibration occurring in the Successive Phases of the Earthquake Motion.

1st Preliminary Tremor.	2nd Preliminary Tremor.	1st and 2nd Ph., Princ. Portion.	3rd Phase, Principal Portion.	4th and 5th Ph., Princ. Portion; End Portion
P_1	P_1	P_1	P_1	P_1
P_2	P_2	P_2	—	P_2
$P_{2,3}$	$P_{2,3}$	$P_{2,3}$	$P_{2,3}$	$P_{2,3}$
P_3	P_3	P_3	P_3	P_3
—	—	—	—	P_4
P_5	P_5	P_5	P_5	—
—	—	—	—	$P_{5,6}$
P_6	P_6	P_6	P_6	P_6
—	—	—	P_7	
$P_{7,8}$	$P_{7,8}$	$P_{7,8}$	$P_{7,8}$	
—	P_8	—	—	
—	P_9	P_9	P_9	
P_{10}	P_{10}	P_{10}	P_{10}	
	P_{11}	P_{11}		
	P_{12}	P_{12}		
	P_{13}	P_{13}		
	—	P_{14}		
	—	P_{15}		
	⋮			
	P_{19}			

(*i*) According to the above table, the longest period P_{19} occurred in the 2nd preliminary tremor, while the two next longest ones, P_{15} and P_{14}, occurred only in the 1st and 2nd phases of the principal portion. Again the three next longest periods, P_{13}, P_{12}, and P_{11}, occurred only in the three above-named sections. On the whole the periods characterizing the 2nd preliminary tremor seem to be identical with those characterizing the 1st and 2nd phases of the principal portion, with the difference that similar periods did not have the same amplitudes in these different sections of motion, as follows:—

(i) In the 2nd preliminary tremor, the periods of the predominating larger vibrations were P_5 to P_{12};

(ii) In the 1st and 2nd phases of the principal portion, the vibrations of the periods P_1 to P_6 were small, those of the periods P_7 to P_{13} being much larger than the rest. The vibrations of P_2 and $P_{2,3}$ were here much smaller than in the preceding section.

(*ii*) With respect to the 1st preliminary tremor and the 3rd phase of the principal portion, we see that the periods occurring in these two sections are nearly alike; the longest period being P_{10} in each case. The principal differences between the two sections in question were as follows:—

(i) All the vibrations, with the exception of that of the period P_1, are much greater in the 3rd phase of the principal portion than in the 1st preliminary tremor.

(ii) The predominating vibrations in the 1st preliminary tremor are those of the periods P_1 to P_3.

(iii) The most active vibrations in the 3rd phase of the principal portion are those of the periods $P_{2,3}$ to P_8.

(*iii*) In the 4th and 5th phases of the principal portion and in the tail, or end portion, the predominating periods were P_2 to $P_{5,6}$.

The periods occurring throughout the successive phases of the earthquake motion were P_1 to P_6.

132. *Range of Motion (2a) corresponding to the different Periods, P's.* The following table, giving the ranges of motion, $2a$'s, corresponding to the different periods P's, has been formed from the data contained in Table XXXV, and relates to the 12 places of Tokyo, Ōsaka, Kōbe, Tadotsu, Taihoku, Taichu, Tainan, Birmingham, Quarto-Castello, Cheltenham, Washington, and Tacubaya.

In Table XXXVIII the "mean $2a$" is the average value of the max. $2a$'s in one or the other of the two horizontal components at the different stations, corresponding to a given period; the "greatest $2a$" being the absolutely largest among these max. $2a$'s. The max. $2a$'s evidently due to the proper pendulum oscillation, which are marked each with an *asterisk*(*), have been excluded in the deduction of the mean $2a$'s.

TABLE XXXVIII. Kangra Earthquake.
$2a$ corresponding to the different P's.

Period.	Greatest $2a$.	Mean $2a$
P_1	mm 0.53	mm 0·23
P_2	1.20	0.47
$P_{2,3}$	12.90* (next greatest, 3.67)	1.28
P_3	11.90* („ „ , 2.40)	0.60
P_4	2.00	0.84
P_5	1.58	0.85
$P_{5,6}$	2.33	0.96
P_6	2.25	0.84
P_7	11.70* (next greatest, 6.24)	4.48
$P_{7,8}$	3.10	1.22

Period.	Greatest $2a$.	Mean $2a$.
P_8	2.70 mm	1.68 mm
P_9	4.50	1.01
P_{10}	4.80	1.66
P_{11}	6.65	2.70
P_{12}	5.80	2.04
P_{13}	10.80* (next greatest, 2.00)	1.06
P_{14}	1.30	1.30
P_{15}	0.14	0.14
⋮	⋮	⋮
P_{19}	2.27	2.27

From Table XXXVIII it will be seen that the mean $2a$'s corresponding to the 4 periods, P_1, P_2, P_3, and P_4, are roughly in the ratios of 1 : 2 : 3 : 4, showing an increase of the amplitude with the period. The $2a$'s for P_4, P_5, $P_{5,6}$, and P_6 were nearly constant, varying only between 0.84 and 0.96 mm. The amplitude seems to reach its greatest value approximately for P_{11}, as is graphically illustrated in Fig. 19. The curve, drawn with free hand through the mean positions between the different dots (•), passes through the origin of co-ördinates, which agrees with the fact that quick vibrations of macroseismic nature are very slight in the teleseismic motion. The relation between the different periods, P_1, P_2, ..., and the corresponding *greatest* $2a$'s, illustrated in Fig. 18, presents the same general character as in the case considered above.

The results thus far arrived at respecting the dependence of the amplitude on the period may be summarized as follows :—

In the teleseismic motion, the $2a$ increases with the period, from nearly zero to a maximum (absolute maximum in a single horizontal component=6.65 mm) for the period P_{11}=45.4 sec.

133. ***The Order of Occurrence of the different Periods in the Principal Portion of the Earthquake Motion.*** The horizontal pendulum observation of earthquakes, made in Tokyo between 1898 and 1904, has shown that, in the teleseismic motion due to a great source of disturbance, the different periods of vibration in the *principal portion* generally tend to occur in a descending order, that is to say, the vibrations at the commencement of the 1st phase (3rd section) has the longest period, those in the subsequent phases having periods of successively decreasing length.* The observation of the Kangra earthquake at the different stations also indicates the same fact, as is shown in the 3rd column of Table XXXIX, in which the periods in the 1st to 5th phases of the principal portion (3rd to 7th sections) are given in terms of the P's in the order of their occurrence. This peculiar characteristic of the earthquake motion is to be most clearly ascertained with seismographs whose " steady mass " has a long oscillation period.

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* See the *Publications*, No. 21, p.p. 84-86.

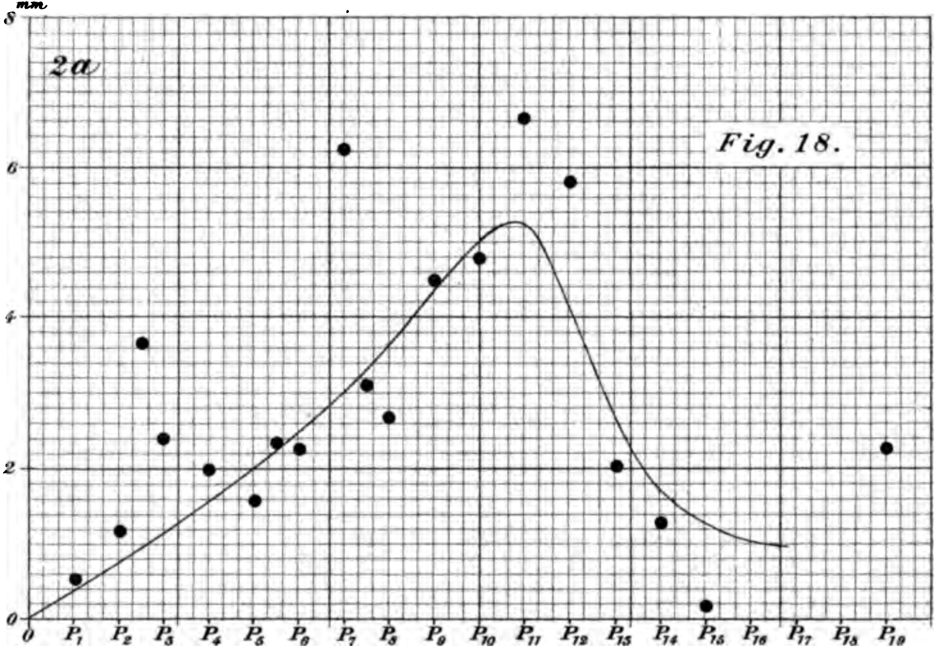
Pl. XI.

Indian Earthquake of 1905.

Relation between the Period and Amplitude.

Fig. 18.........**$2a$ = Absolutely greatest max. motion.**

Fig. 19..........**$2a$ = mean value of max. $2a$'s.**



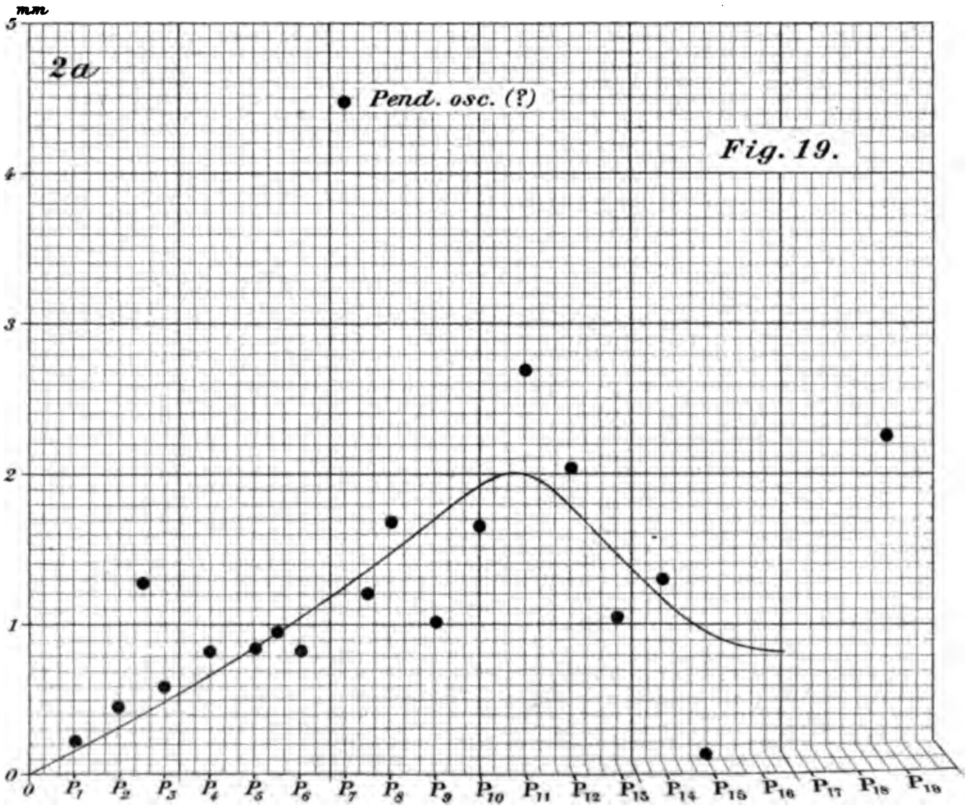


TABLE XXXIX. Kangra Earthquake. The Order of Occurrence of the different Periods in the 2nd Preliminary Tremor and in the Principal Portion of the Earthquake Motion.*

Station.	2nd Preliminary Tremor.	1st to 5th Phases, Principal Portion.
Tokyo (EW)	$P_{9}\ P_{12}\ P_{13}\ P_{10}\ \left\{\begin{matrix}P_{6}\\P_{2}\end{matrix}\right.$	$\left\{\begin{matrix}P_{14}\\P_{2,3}\end{matrix}\right.\ P_{13}\ P_{7}\ P_{4}\ \left\{\begin{matrix}P_{2,3}\\P_{5}\end{matrix}\right.\ P_{2,3}\ P_{2,3}\ P_{2,3}$
„ (NS)	$\left\{\begin{matrix}P_{11}\\P_{5,6}\end{matrix}\right.\ \left\{\begin{matrix}P_{8}\\P_{13}\end{matrix}\right.\ \left\{\begin{matrix}P_{11}\\P_{10}\end{matrix}\right.$	$P_{10}\ P_{12}\ P_{10}\ \left\{\begin{matrix}P_{2,3}\\P_{5,6}\end{matrix}\right.\ P_{2,3}\ \left\{\begin{matrix}P_{5}\\P_{2,3}\end{matrix}\right.\ P_{2,3}\ P_{5,6}$
„ (Vertical)	....	$P_{11}\ P_{7,8}\ P_{5,6}\ P_{3}\ P_{3}$
Ōsaka (EW)	$P_{2,3}\ P_{8}\ P_{6}\ P_{7,8}$	$P_{5,6}\ P_{7}\ P_{6}\ \left\{\begin{matrix}P_{6}\\P_{2,3}\end{matrix}\right.\ \left\{\begin{matrix}P_{5,6}\\P_{2,3}\end{matrix}\right.\ \left\{\begin{matrix}P_{4}\\P_{3}\\P_{2,3}\end{matrix}\right.$
Kōbe (NS)	....	$P_{9}\ P_{13}\ P_{10}\ P_{7}\ \left\{\begin{matrix}P_{8}\\P_{5}\end{matrix}\right.\ \left\{\begin{matrix}P_{5,6}\\P_{2}\end{matrix}\right.\ \left\{\begin{matrix}P_{4}\\P_{2,3}\end{matrix}\right.$
Tadotsu (EW)	....	$\left\{\begin{matrix}P_{10}\\P_{4}\end{matrix}\right.\ P_{7}\ \left\{\begin{matrix}P_{5}\\P_{2,3}\end{matrix}\right.\ P_{2,3}$
Taihoku (EW)	....	$\left\{\begin{matrix}P_{10}\\P_{2,3}\\P_{1}\end{matrix}\right.\ P_{7,8}\ P_{3}\ \left\{\begin{matrix}P_{2,3}\\P_{1}\end{matrix}\right.$
Washington (NS)	....	$P_{11}\ P_{12}\ P_{7}\ P_{5}\ P_{3}$
Cheltenham (EW)	....	$P_{15}\ \left\{\begin{matrix}P_{13}\\P_{3}\end{matrix}\right.\ \left\{\begin{matrix}P_{11}\\P_{5,6}\end{matrix}\right.\ \left\{\begin{matrix}P_{7,8}\\P_{3}\end{matrix}\right.\ P_{5}\ \left\{\begin{matrix}P_{5}\\P_{3}\end{matrix}\right.\ P_{3}$
„ (NS)	$\left\{\begin{matrix}P_{7,8}\\P_{2}\end{matrix}\right.\ P_{2,3}\ P_{11}\ P_{6}$	$\left\{\begin{matrix}P_{15}\\P_{6}\end{matrix}\right.\ \left\{\begin{matrix}P_{12}\\P_{3}\end{matrix}\right.\ P_{7,8}\ P_{4}\ P_{5}\ P_{3}\ P_{3}$
Tacubaya (EW)	....	$P_{14}\ P_{11}\ P_{9}\ P_{6}\ P_{5,6}\ P_{4}\ \left\{\begin{matrix}P_{3}\\P_{4}\\P_{5}\end{matrix}\right.$

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*The different periods occurring simultaneously in one and the same epoch are indicated by a bracket.

Station.	2nd Preliminary Tremor.	1st to 5th Phases, Principal Portion.
Tacubaya (NS)	....	P_{11} P_{10} P_6 P_6 P_3 P_3
Potsdam (EW)	....	$\left\{\begin{matrix}P_5\\P_1\end{matrix}\right.$ P_{11} $\left\{\begin{matrix}P_{7,8}\\P_2\\P_1\end{matrix}\right.$ $P_{7,8}$ P_5 P_3 $\left\{\begin{matrix}P_3\\P_5\end{matrix}\right.$
Göttingen (NS)	....	P_{12} P_9 $P_{7,8}$ $\left\{\begin{matrix}P_8\\P_{2,3}\end{matrix}\right.$ $\left\{\begin{matrix}P_3\\P_2\end{matrix}\right.$ $\left\{\begin{matrix}P_3\\P_2\end{matrix}\right.$

Thus it will be seen that in the majority of cases, the series began with slow vibrations of periods, P_{11} to P_{15}, thence becoming successively quicker towards the end of the principal portion. Especially, at Tokyo (EW, NS, and Vertical), Tadotsu (EW), Taihoku (EW), Cheltenham (EW and NS), Tacubaya (EW and NS), and Göttingen (NS), the succession of the different periods was in a perfect decreasing order.

It is here to be noted that what was said above respecting the order of occurrence relates only to the predominating vibrations in the principal portion, some of the small vibrations with shorter periods occurring more or less in the different sections of the earthquake motion.

134. ***Periods Occurring in the 2nd Preliminary Tremor.*** The vibrations in the 2nd preliminary tremor do not generally indicate a definite order of occurrence according to the lengths of their periods. There seems, however, to exist a tendency for an increasing order of periods, as shown, for a few places, in the 2nd column of Table XXXIX.

Chapter IX. Earthquake motion propagated along the major arc and the repetition of the motion propagated along the minor arc. General remarks on the propagation velocity.

W_2 MOTION, OR THE EARTHQUAKE PROPAGATED ALONG THE MAJOR ARC.

135. ***Observation at Calcutta and Bombay.*** Let us first consider the Milne horizontal pendulum observation of the W_2 wave, or the earthquake motion propagated along the major arc, at the two Indian stations of Alipore (Calcutta) and Colaba (Bombay), whose distances from the epicentre of the Kangra earthquake were only 13° 42′ and 13° 32′ respectively.

(*i*) *Alipore* (Calcutta). The preliminary tremor lasted $3^m 24^s$, the motion being largest for the first 29^m of the principal portion.

W_2 began at $3^h\,57^m\,30^s$, or $3^h\,5^m\,30^s$ after the commencement of the earthquake disturbance there, the 1st maximum group lasting for about 20^m:—$2a = 1.6$ mm (actual reading). The principal maximum group occurred 14^m later on.

(*ii*) *Colaba* (Bombay). The preliminary tremor lasted $3^m 31^s$, the motion being greatest for the first $18\frac{1}{2}^m$ of the principal portion.

W_2 began at $4^h\,17^m$, or $3^h\,23^m\,52^s$ after the commencement of the earthquake disturbance there; the max. group ($2a = 0.6$ mm, actual reading) occurring at $4^h\,24^m$. The motion lasted altogether for about 32^m, the last slight max. group in this portion possibly belonging to the W_3 motion.

Taking the average from the Alipore and Colaba observations, we obtain:—Time interval between the commencement of the principal portion and that of the W_2 motion $= 3^h\,14^m\,41^s$, the corresponding epicentral distance being $13^\circ 37'$. In the cases of these two stations, the W_2 recorded by the seismographs seems to be the 3rd phase of the principal portion of the major arc propagation; the time interval above obtained being nearly equal to the time required by the wave of that phase in making one complete circuit of the earth. Thus, if the velocity (v_5) of the 3rd phase of the principal portion be assumed to be 3.2 km/sec., we have:—

$$\varDelta t_5 = \frac{s - 2x}{v_5} = 201.7^{\text{min.}} - 0.01008\, x^{\text{km}},$$

in which s denotes the length of the earth's circumference, x the epicentral distance of a given station, and $\varDelta t_5$ the interval between the times of arrival at the latter of the phase under consideration along the minor and the major arcs. The maximum value of $\varDelta t_5$, corresponding to $x=0$, is according to the above formula, about $3^{\text{h}}\ 21.^{\text{m}}7$.

136. ***British Stations.*** As shown later on, there are, in the W_2 motion, two predominating sets of vibrations whose periods are approximately equal to P_5 (=about 20 sec.) and P_6 (=about 25 sec.) respectively; the P_6 vibrations occurring earlier than P_6 ones. Thus it is to be readily understood that the record of the W_2 motion differs much according to the oscillation period of the "steady mass" of the seismograph. This circumstance is well illustrated by the Milne horizontal pendulum seismograms obtained at the British stations. (See §§ 67—71.)

Shide records. The maximum part of W_2 in the C-pendulum record began just at the termination of that in the B-pendulum one. As the natural oscillation period of the C-pendulum was 20 sec., while that of the B-pendulum was 25 sec., this shows that, in the W_2 motion, the vibrations of period of about 25 sec. occurred earlier than those of about 20 sec.

Edinburgh record. The W_2 motion began later than the appearance of the maximum group, marked *g*, in Shide records. This was probably due to the shortness of the pendulum period of the Edinburgh instrument.

Kew record. The first max. group in the W_2 motion corresponds to that marked *e* in the Shide *C*-pendulum record, which occurred at 3^h 36.4^m. The 2nd max. group, which began at 3^h 49^m, corresponds to that marked *g* in the Edinburgh record.

Liverpool record. The max. group corresponds to the group *e* in the Shide *C*-pendulum record.

Paisley record. The record was nearly similar to that for Liverpool. (See Pls. XVIII and XIX, the *Publications*, No. 23.)

137. ***Querce.*** As an illustration of the identification of the corresponding epochs in the movements propagated along the minor and major arcs, I shall here briefly consider the observation at Querce. (See § 34). The W_2 motion in the NE-SW component is much smaller than that in the NW-SE component. The latter component may be summarized as follows :—

Earthquake Commencement $= 0^h$ 59^m 8^s.

(*a*) 1^h 6^m 24^s......Commencement of 2nd preliminary tremor.

(*b*) 1 20 09 ...... „ 3rd phase of princ. portion.

(*c*) 1 39 07 ......Motion active.

(*d*) 1 28 56 ......Greatest max. group of pendulum oscillation.

(*e*) 1 39 07—2^h 1^m 7^s......Motion more or less active.

(*f*) 3 10 50 ......Commencement of the W_2 motion.

(*g*) 3 28 12 ......Motion became larger, $2a = 0.12$ mm.

(*h*) 3 43 19 ...... „ increased, $2a = 0.14$ mm.

(*i*) 3 47 50 ...... „ most active, $2a = 0.27$ mm.

(*j*) 3 57 14 ......End of motion.

Let us, for the sake of trial, suppose that (*i*) of the W_2

motion corresponds to (d) of the W_1 motion, or the earthquake proper; (f) and (b) being also supposed to be corresponding vibrations. On these assumptions we have :—

$$\begin{array}{l}\left\{\begin{array}{l}(i)\ldots\ldots 3^{h}\ 47^{m}\ 50^{s}\\ (f)\ldots\ldots 3\quad 10\quad 50\end{array}\right.\\ \hline \text{Difference}=\ \ 37^{m}\ 00^{s}\end{array}\qquad\qquad \begin{array}{l}\left\{\begin{array}{l}(d)\ldots\ldots 1^{h}\ 28^{m}\ 56^{s}\\ (b)\ldots\ldots 1\quad 20\quad 09\end{array}\right.\\ \hline \text{Difference}=\ \ 8^{m}\ 47\end{array}$$

Therefore :

$$\frac{(i)-(f)}{(d)-(b)}=\frac{37^{m}\,00^{s}}{8^{m}\,47^{s}}=4.2\ldots\ldots\ldots\ldots\ldots(1)$$

This number, being, under our supposition, the ratio of the duration of the 3rd phase of the principal portion in the W_2 motion to that in the W_1, ought to be approximately equal to the ratio of the major to the minor arc of the earth between Florence and the earthquake origin, as the duration of a given phase of the motion increases nearly in proportion to the distance. We have :—

$$\frac{\text{major arc}}{\text{minor arc}}=\frac{308^\circ\ 06'}{51^\circ\ 54'}=5.2\ \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

which ratio may be regarded as being sufficiently near to that of the durations previously obtained, in view of the very approximate nature of the discussion in question. As the ratio in (1), however, is greater than that in (2), it is perhaps better to regard (f) as corresponding to some epoch in the 2nd phase of the principal portion.

138. ***Tacubaya, Cheltenham, and Washington.*** As examples of the combination of the observations relating to the W_2 motion, at two or more neighbouring stations, let us next compare the Tacubaya, Cheltenham, and Washington records.

(*i*) *Comparison of EW Component Seismograms.*

TABLE XL. Times of Commencement of the different Phases of motion at Tacubaya and Cheltenham.

Phase of motion	Tacubaya.	Cheltenham.	Time difference:— Tacubaya— Cheltenham.
1st Prel. Tremor.	$1^{h}\ 11^{m}\ 25^{s}$	$1^{h}\ 8^{m}\ 39^{s}$	$+\ 2^{m}\ 46^{s}$
2nd Prel. Tremor.	1 28 3	1 23 21	+ 4 42
1st Phase, Princ. Portion.	1 43 45	1 35 35	+ 8 10
2nd Phase, Princ. Portion.	1 50 27	1 39 28	+10 59
Do.	1 53 30	1 42 30	+11 0
3rd Phase, Princ. Portion.	2 1 49	1 49 12	+12 37
W_2: Max. Phase.	2 43 46	2 58 19	−14 33

The EW component seismograms obtained at Tacubaya and Cheltenham enable us to make a fairly accurate comparison of the times of commencement of the different phases of motion at these two places. As the arcual distances of Tacubaya and Cheltenham from the centre of the earthquake disturbance are 128 47′ and 105° 22′ respectively, the vibrations propagated along the minor arcs of the earth ought to reach the latter place earlier than the former, the reverse being the case with those propagated along the major arcs, or the W_2 waves. Now, according to the preceding table, the time-difference of arrival at Tacubaya and Cheltenham was $2^m\ 46^s$ for the commencement of the 1st preliminary tremor, thence gradually increasing up to $12^m\ 37^s$ for the 3rd phase of the principal portion. The time difference might be greater for the later phases of the same portion, but the further identification was not possible. For the maximum phase of the W_2 motion, the corresponding difference comes out, as ought to be, negative and amounted to $14^m\ 33^s$.

(*ii*) *Calculation of the Transit Velocity from the seismographic records at any two places.* From the seismographic records taken at any two places at different distances from the earthquake origin, we can accurately calculate the transit velocity of the 3rd phase of the principal portion, by comparing it with the most active part in the W_2 motion, even when the clock indication at each place is slightly wrong. Thus let τ_1 denote the difference in the times of arrival at the two given stations of the 3rd phase of the principal portion of the seismic waves propagated along the minor arcs, and $(-\tau_2)$ the corresponding quantity for the waves propagated along the major arcs. If the clock indications at the two places be perfectly accurate, τ_1 ought to be equal to τ_2, supposing the identifications of the W_1 and W_2 waves to be correct. Let $\delta\tau$ be the *relative* clock correction to be applied to τ_1 and τ_2 necessary for getting the true time differences. We then have:—

$$\left\{\begin{array}{l} \delta\tau = -\dfrac{\tau_1-\tau_2}{2}\,; \\[2ex] v_5 = \dfrac{2\delta x}{\tau_1+\tau_2}\,; \end{array}\right.$$

where v_5 denotes the velocity of propagation of the 3rd phase of the principal portion, and δx is the difference between the arcual distances from the earthquake origin of the two given stations.

To apply the above equations to the cases of Tacubaya and Cheltenham, we have:

$$\left\{\begin{array}{l} \delta x = 128^\circ\ 47' - 105^\circ\ 22' = 23^\circ\ 25' \\ \tau_1 = 12^{m}\ 37^{s} \\ -\tau_2 = -14^{m}\ 33^{s} \end{array}\right.$$

We find therefore:—

$$\left\{\begin{array}{l} \delta\tau = +58 \text{ sec.} \\ v_5 = 3.17 \text{ km per sec.} \end{array}\right.$$

Using this time correction, we may calculate the velocities of the different phases of the earthquake motion from the time differences between Tacubaya and Cheltenham, given in the preceding table, as follows :—

$$\left\{\begin{aligned} v_1 &= \frac{23^\circ\ 25'}{(2^m\ 46^s)+58^s} = 11.5 \text{ km/sec.} \\ v_2 &= \frac{23^\circ\ 25'}{4^m\ 42^s+58^s} = 7.6 \\ v_3 &= \frac{23^\circ\ 25'}{8^m\ 10^s+58^s} = 4.7 \\ v_4 &= \frac{23^\circ\ 25'}{10^m\ 59^s+58^s} = 3.6 \end{aligned}\right.$$

These values of the velocities agree very well with those given in a later §.

(*iii*) *Comparison of NS Component Seismograms.*

TABLE XLI. Times of Commencement of the different Phases of motion at Cheltenham, Washington, Tacubaya.

Phase of motion.	Cheltenham.	Washington.	Tacubaya.	**Time Difference: Tacubaya—(Chelt. & Wash.)**
1st Preliminary Tremor.	$1^h\ 8^m\ 38^s$	$1^h\ 8^m\ 25^s$	$1^h\ 11^m\ 25^s$	$+\ 2^m\ 53^s$
2nd „ „	1 23 23	1 23 27		
1st Ph., Princ. Portion.	1 35 39	1 35 36		
3rd Ph., Princ. Portion.	1 51 10	1 51 16		
Max. Motion, in the above phase.	1 52 15	1 52 39	2 11 18	+ 18 51
4th Ph., Princ. Portion.	2 3 2	—		
W_2 (commencement)	—	2 27 28		
W_2 (principal portion)	2 51 27	2 52 30		
W_2 (most distinct part.)	—	2 58 43	2 48 25	−10 18

The arcual distances of Cheltenham and Washington from the earthquake origin are nearly equal to one another, being respectively 105° 22′ and 105° 17′. It is, therefore, not possible to make any calculation based on the time differences for these two places. Table XLI shows, however, that the times of arrival of the different phases of the seismic motion at these two stations were practically identical. Taking means from the two seismograms, we find:—

		h	m	s
Cheltenham, Washington.	1st preliminary tremor.	1	8	32
	2nd " "	1	23	25
	1st phase, principal portion.	1	35	38
Mean epicentral distance. =105° 20′	3rd " , "	1	51	13
	Max. in the 3rd phase.	1	52	27
	Principal portion in W_2	2	51	59

Taking the average from Tables XL and XLI, we have:— Difference between the times of occurrence at Tacubaya and two American stations of the most active part of the W_2 motion = $12^{m}\,26^{s}$; the corresponding propagation velocity is, using the same clock correction before found.

$$v_5 = \frac{23°\ 27'}{12^{m}26^{s} + 58^{s}} = 3.23 \text{ km/sec.}$$

139. ***Tokyo Observation.*** To identify the corresponding vibrations in the three components, I give in the following table the time of commencement, $2a$, and T, of the successive epochs in the records furnished by the two long-period horizontal pendulums and the vertical motion instrument. (See § § 14 to 20.)

Epoch.	EW Component.			NS Component.			Vertical Component.		
	Time of occurrence.	$2a$	T	Time of occurrence.	$2a$	T	Time of occurrence.	$2a$	T
	h m s	mm	sec	h m s	mm	sec	h m s	mm	sec
A (Beginning of 2nd P. T.)	1 06 25	{2.5 5.8	36.4 49.7	1 06 25	{2.33 3.95	11.6 46.0	1 06 25	—	—
B	1 11 05	4.50	37.7	1 10 28	3.53	43.7	—	—	—
C (Beginning of 2nd Ph., P.P.)	1 15 44	1.08	53.0	1 16 15	3.50	42.5	1 16 45	0.07	45.2
D (Beginning of 3rd Ph., P.P.)	1 20 34	6.24	27.6	(Pointer went out)	—	—	1 20 31	0.28	29.7
E	1 22 24	2.40	16.8				1 22 00	0.13	22.3
F	1 23 31	3.67	10.3	—	—	—	1 23 07	0.29	14.7
G	—	—	—	1 27 02	1.70	10.3	—	—	—
H (Beginning of W_2)	—	—	—	2 43 37	0.10	45.0	—	—	—
I	3 15 08	0.067	30.0	—	—	—	—	—	—
J	—	—	—	3 21 17	Small	Slow.	—	—	—
K (1st Max. of W_2).	3 24 31	0.13	24.3	3 25 17	0.10	25.4	—	—	—
L (2nd Max: 3rd Ph., P.P. of W_2).	3 33 37	0.19	19.4	—	—	—	3 33 22	Small	—
M	—	—	—	3 36 30	0.12	19.5	3 37 31	„	19.5
N	4 24 52	Small	44.0	—	—	—	—	—	—

(*H*) and (*L*) in the foregoing table seem to correspond respectively to the commencement of the 1st phase and the commencement of the 3rd phase, of the principal portion of the W_2 motion. (For the identification of (*L*), or the 2nd max. group of W_2, the reader is also referred to § 141.) According to this supposition, we obtain, by taking the means from the three components, the following value of the duration(=$y_{3.4}$) of the 1st and 2nd phases of W_2:—

(*L*) ....$3^h 33^m 30^s$
(*H*)..........2 43 37

Difference $= y_{3.4} = 49^m 53^s$

As the duration ($y_{3,4}$) of the 1st and 2nd phases of the principal portion of the W_1 motion or the earthquake proper was $7^m\ 21^s$ (§ 20), we have

$$\frac{y_{3,4}\ (W_2)}{y_{3,4}\ (W_1)}=\frac{49^m\ 53^s}{7^m\ 21^s}=6.8.$$

This ratio is not much different from the ratio of the major and minor arcs between Tokyo and the earthquake origin, namely,

$$\frac{308°\ 34'}{51°\ 26'}=6.0.$$

Again, the velocity (v_5) of propagation of the 3rd phase of the principal portion may be deduced from the comparison of the W_1 and W_2 vibrations, as follows :—

$$v_5=\frac{360°-(2\times 51°\ 26')}{3^h\ 33^m\ 30^s-1^h\ 20^m\ 33^s}=3.58 \text{ km per sec.}$$

140. ***Osaka Observation.*** (See § 22). The period of the principal vibrations in the most active part of the W_2 motion was 18.5 sec., while those in the preceding phase were 25.1 and 20.4 sec.; the vibrations with periods similar to one or both of these latter occurring in the 1st and 2nd preliminary tremors, and the 1st, 2nd, and 4th phases of the principal portion, of the W_1 motion, or the earthquake proper. The diagram did not indicate, in the 3rd phase of the principal portion, the vibrations with a period of exactly 18.5 sec.; but it is likely that the existence of such movements there was masked by large proper pendulum oscillations which partly confused the record.

The times of occurrence of the first feeble and the most active parts in the W_2 motion, denoted by t_4' and t_5' were respectively as follows :—

$$t_4'=3^h\ 22^m\ 30^s,\quad t_5'=3^h\ 40^m\ 56^s;$$

the time difference, $t_5'-t_4'$, being $18^m\,26^s$. t_4' and t_5' may probably be taken as marking approximately the commencements respectively of the 2nd and 3rd phases of the principal portion of the W_2 motion; the corresponding times in the earthquake proper (W_1), denoted by t_4 and t_5, being respectively

$$t_4=1^h\,16^m\,51^s \text{ (approximate)},\quad t_5=1^h\,20^m\,9^s;$$

The difference, t_5-t_4, is $3^m\,18^s$.

Now the arcual distances between Osaka and the earthquake origin are as follows :—

$$\begin{cases} x=\ 48°\,19' \;\ldots\ldots \text{ Along the minor arc.} \\ x'=360°-x=311\ \ 41 \;\ldots\ldots\ \text{,,}\quad \text{,,}\quad \text{major arc.}\end{cases}$$

We thus obtain :—

$$\frac{360°-x}{x}=6.5\,;\quad \frac{t_5'-t_4'}{t_5-t_4}=5.6.$$

The approximate equality of these two ratios tends to prove that the assumed identifications of the phases in the W_2 and W_1 movements are roughly correct.

Under this supposition, the velocities, v_4 and v_5, respectively corresponding to the commencements of the 2nd and 3rd phases of the principal portion may be deduced from the observation of W_1 and W_2 movements, as follows :—

$$\begin{cases} v_4=\dfrac{x'-x}{t_4'-t_4}=\dfrac{263°\ 22'}{2^h\ 5^m\ 39^s}=3.88 \text{ km/sec.} \\ v_5=\dfrac{x'-x}{t_5'-t_5}=\dfrac{263°\ 22'}{2^h\,20^m\,47^s}=3.47 \quad \text{,,}\end{cases}$$

141. ***Time of Occurrence and Propagation Velocities of the W_2 Motion.*** The W_2 motion generally presented a series of maxima, the 1st and 2nd being specially well defined. As will be seen from Table XLII, the 2nd maximum was in most cases greater than the 1st. The following table gives, for each of a number of the stations where the earthquake was observed with large time-scale instruments, the epicentral distance (x), the times (t_1 and t_5) of commencement of the 1st preliminary tremor and the 3rd phase of the principal portion, and the times (t', t_4' and t_5') of commencement of the W_2 motion and its 1st and 2nd maxima.

TABLE XLII. Observation of W_2 Motion.
Times of Occurrence.* [Open Seismograms.]

Place.	Epicentral Distance $=x$.	W_1 (Eq. Proper.)		W_2		
		Time of occurrence $=t_1$	Commencement of 3rd Ph., Princ. Portion $=t_5$	Commencement $=t'$	1st Maximum Phase $=t_4'$	2nd Maximum Phase $=t_5'$
Tokyo (EW)	51°26′	$0^h 59^m 08^s$	$1^h 20^m 34^s$	$2^h 43^m 37^s$	$3^h 24^m 31^s$	$3^h 33^m 37^s$
„ (NS)			——		3 25 17	3 36 30
„ (Vertical)			1 20 31		——	3 33 22
Osaka (EW)	48 19	0 58 51	1 19 52	——	3 22 30	3 35 09 3 39 40
Tadotsu (EW)	47 02	0 58 49	1 18 52		3 31 22	3 36 35
Potsdam (EW)	49 48	0 58 46	1 17 29	3 20 31	3 25 31	——
„ (NS)			1 17 39	——	——	3 40 16
Triest	49 52	0 58 44	——	3 13 56	3 54 26	——
Göttingen	51 45	0 58 55	1 20 18	——	3 20 —	3 45 —
Querce	51 54	0 59 08	1 20 09	3 10 50	3 28 12	3 43 19
Birmingham (EW)	58 49	1 00 35	1 25 22	3 01 27	3 18 22	——

---

* t_5' and t_5'' are respectively the times of commencement of the 1st and 2nd maxima in the W_2 motion.

Station.	Epicentral Distance $=x$.	W_1 (Eq. Proper).		W_2		
		Time of occurrence $=t_1$	Commencement of 3rd Ph., Princ. Portion $=t_5$	Commencement $=t'$	1st Maximum Phase $=t'_4$	2nd Maximum Phase $=t'_5$
		h m s	h m s	h m s	h m s	h m s
Washington (NS).	105°17′	1 08 25	1 51 16	2 27 28	2 52 30	2 58 43
Cheltenham (EW).	105 22	1 08 39	1 49 12	——	——	2 58 19 3 02 24 3 09 05
„ (NS).			1 51 10	——	2 51 27	2 58 32
Tacubaya (EW).	128 39	1 11 25	2 01 49	2 16 41	2 43 46	——
„ (NS).			2 09 21	——	——	2 48 25

The different places contained in the above table, with the exception of Triest, may be divided, according to the epicentral distance into two groups as follows.

TABLE XLIII. Mean Group Values of Times of Occurrence of W_2 Motion.

Group.	Epicentral Distance $=x$.	Time of Occurrence.			
		3rd Ph., P.P. of $W_1=t_5$	Commencement of $W_2=t'$	1st Max. of $W_2=t'_4$	2nd Max. of $W_2=t'_5$
		h m s	h m s	h m s	h m s
(i) Tokyo, Osaka, Tadotsu, Querce, Potsdam, Göttingen, Birmingham.	51° 18′	1 20 23	2 43 37*	3 24 21	3 38 58
(ii) Washington, Cheltenham, Tacubaya.	113° 06′	1 54 25	2 22 05	2 49 14	2 55 09

(* Based on the Tokyo observation alone.)

Propagation Velocities, calculated by "Direct Method." Table XLIV gives the transit velocities of the W_2 motion, obtained by the formula

$$\text{Velocity}=\frac{360^\circ-x}{t_4'-t_0},\ \text{or}\ \frac{360^\circ-x}{t'_5-t_0};$$

t_0 being the time of earthquake occurrence at the origin. The velocity relating to W_1 has been obtained in the usual way.

TABLE XLIV. Propagation Velocities, calculated by "Direct Method." [Comparison of W_1 and W_2 Velocities.]

Group.	v_5 = Velocity of the 3rd Phase of Princ. Portion, W_1.	v'_4 = Velocity of 1st Maximum of W_2.	v'_5 = Velocity of 2nd Maximum of W_2.	Velocity of Commencement of W_2.
	km/sec.	km/sec.	km/sec.	km/sec.
i	$v_5=3.11$	$\frac{308^\circ\ 42'}{2^h\ 34^m\ 33^s}=3.70$	$\frac{308^\circ\ 42'}{2^h\ 49^m\ 10^s}=3.38$	$\frac{308^\circ\ 34'}{1^h\ 53^m\ 49^s}=5.02$
ii	" 3.25	$\frac{246^\circ\ 54'}{1^h\ 59^m\ 26^s}=3.83$	$\frac{246^\circ\ 54'}{2^h\ 05^m\ 21^s}=3.65$	$\frac{246^\circ\ 54'}{1^h\ 32^m\ 17^s}=4.96$

Thus the velocity v_5' of the 2nd, or greatest, maximum in the W_2 motion is, for Group (i), very nearly equal to the velocity v_5 of the 3rd phase of principal portion of W_1, and it seems that these two epochs are corresponding ones; the identification of the 2nd maximum in the W_2 motion of Group (ii) being probably not correct.

Propagation Velocity, calculated by "Difference Method." Calculating, for the 2nd maximum of Group (i), the velocity by the "difference method," that is to say, by taking the time and distance differences between the minor and major arc propagations, we obtain :—

$$v_5'=\frac{360^\circ-2x}{t'_5-t_5}=\frac{257^\circ\ 24'}{2^h\ 18^m\ 35^s}=3.44\ \text{km/sec.}$$

This value of the velocity is not much different from that obtained by the "direct method."

142. W_2 Motion observed with Milne Horizontal Pendulums. The following table gives the results relating to the W_2 motion as registered by Milne horizontal pendulums at 11 different stations of Kew, Edinburgh, Shide, Liverpool, Paisley, San Fernando, Cape Town, Baltimore, Wellington, Alipore, and Colaba.

TABLE XLV. Observation of W_2 Motion: Times of Occurrence.
[Milne Horizontal Pendulum Seismograms.]

Station.	Epicentral Distance $= x$.	W_1 (Eq. Proper). Time of occurrence $= t_1$.	W_1 (Eq. Proper). Commencement of 3rd Ph., Princ. Portion $= t_5$.	W_2 Commencement $= t'$.	W_2 Principal Maximum $= t'_5$.	W_2 2nd Maximum $= t'_6$.
		h m s	h m s	h m s	h m s	h m s
Kew.	58° 05′	1 00 12	1 23 12	—	3 36 54	—
Edinburgh.	58 48	1 00 00	1 22 36	—	—	3 46 54
Shide.	58 52	1 01 00	1 22 42 1 30 00*	3 04 36	3 20 24 3 38 42‡	—
Liverpool.	59 18	1 00 36	1 23 54 1 28 54*	3 28 58	3 37 48‡	—
Paisley.	59 30	1 00 00	1 23 54 1 31 12*	—	—	3 48 24
San Fernando.	66 47	1 02 30	1 27 06	—	3 30 07	—
Cape Town.	85 46	1 02 30	1 36 12	—	3 08 18	—
Baltimore.	104 47	1 10 30	1 53 06	—	3 13 30	—
Wellington.	115 45	1 09 48	1 59 54	—	2 29 18	—
Alipore (Calcutta).	13 42	0 52 00	0 55 24†	3 57 30	4 11 36	—
Colaba (Bombay).	13 28	0 53 08	0 56 39†	—	4 17 00	—

* Time of occurrence of the absolute maximum in W_1.

‡ Time of occurrence of the absolute maximum in W_2.

† Time of the commencement of the principal portion.

The Milne horizontal pendulum observations of the W_2 motion lead to a more uniform result than was the case with those furnished by the mechanically registering instruments. I shall next consider the records obtained at the British stations.

(*i*) *British Stations.* The mean results obtained from the observations at the British stations may be summarized as follows :—

(i) *Kew, Edinburgh, Shide, Liverpool, Paisley.* 3rd phase of the principal portion of W_1, or the earthquake proper, began at $t_5 = 1^h\ 23^m\ 16^s$, the corresponding epicentral distance being 58° 55′.

(ii) *Shide, Liverpool, Paisley.* The absolute maximum trace of W_1 on the seismograms occurred at $t_{\max.} = 1^h\ 30^m\ 02^s$, the corresponding distance being 59° 13′.

(iii) *Shide.* Commencement of the W_2 motion was at $t' = 3^h\ 04^m\ 36^s$; the corresponding, or major arc, epicentral distance being 360° − 58° 52′ = 301° 08′.

(iv) *Shide.* A maximum occurred at $t_4' = 3^h\ 20^m\ 24^s$. The corresponding epicentral distance = 301° 08′, as above.

(v) *Kew, Shide, Liverpool.* The principal maximum occurred at $t_5' = 3^h\ 37^m\ 48^s$, the corresponding major arc distance being 360° − 58° 45′ = 301° 15′.

(vi) *Edinburgh, Paisley.* The 2nd principal maximum occurred at $t'_6 = 3^h\ 47^m\ 39^s$, the corresponding major arc distance being 360° − 59° 09′ = 300° 51′.

Calculating the propagation velocity for the above six cases by " direct method," that is to say, by comparing the respective time of occurrence with that at the earthquake origin, or t_0 ($= 0^h\ 49^m\ 48^s$), we obtain :—

TABLE XLVI. Propagation Velocity of W_1 and W_2 waves, calculated by "Direct Method."

[British Stations.]

Phase of motion.	Epicentral Distance.	Time Interval.	Velocity, calculated by "Direct Method."
		h m s	km/sec.
(i) W_1.. {3rd Phase of Princ. Portion.	$x=$ 58°55′	$t_5 - t_0 = 0\ 33\ 28$	$3.26 = v_5$
(ii) W_1.. Absolute Max.	$x=$ 59 13	$t_{max.} - t_0 = 0\ 40\ 14$	2.73
(iii) W_2.. Commencement.	$360° - x =$ 301 08	$t' - t_0 = 2\ 14\ 48$	4.14
(iv) W_2.. A max.	„ =301 08	$t_4' - t_0 = 2\ 30\ 36$	3.71
(v) W_2...Princ. Max.	„ =301 15	$t_5' - t_0 = 2\ 48\ 00$	$3.32 = v_5'$
(vi) W_2...2nd „ „	„ =300 51	$t_6' - t_0 = 2\ 57\ 51$	3.14

Thus it will be seen that the velocity v_5' of the principal maximum of the W_2 motion is very nearly equal to that of the 3rd phase of the principal portion of the W_1 motion, namely, v_5. Assuming, therefore, (i) and (v) to be corresponding phases in the earthquake movements propagated along the minor and the major arcs, the calculation by the "difference method" gives the following result:—

$$v_5' = \frac{360° - 2x}{t_5' - t_5} = \frac{242°\ 30'}{2^{h}\ 14^{m}\ 32^{s}} = 3.34 \text{ km/sec.};$$

this being practically identical with that deduced by the "direct method."

(*ii*) *San Fernando, Cape Town, Baltimore, Wellington, Alipore, Colaba.* The propagation velocity corresponding to the maximum in the W_2 motion at each of these stations, calculated by "direct method," is given in the following table.

TABLE XLVII. Propagation Velocity of the Maximum Phase in the W_2 Motion, calculated by "Direct Method."

[San Fernando, Cape Town, Baltimore, Wellington, Alipore, Colaba.]

Station.	Epicentral Distance.	Time Interval $=t_5'-t_0$	Velocity $v_5'=\frac{360°-x}{t_5'-t_0}$
San Fernando.	360°− 66°47′=293°13′	2h 40m 19s	3.39 km/sec.
Cape Town.	360 − 85 46 =274 14	2 18 30	3.67
Baltimore.	360 −104 47 =255 13	2 23 42	3.29
Wellington.	360 −115 45 =244 15	1 39 30	4.55*
Alipore.	360 − 13 42 =346 18	3 21 48	3.18
Colaba.	360 − 13 28 =346 32	3 27 12	3.10
Mean..........	....	....	**3.33**

* This velocity is excluded in deducing the average value.

The values of the velocity v_5' given in the above table are, with the exception of that relating to Wellington, fairly uniform, indicating that the velocity in question does not vary with the distance. The average value of v_5' is

3.33 km per sec.

Next, calculating the velocity v_5' for each of the above-mentioned stations, by "difference method," namely, by comparing the time of occurrence of the 3rd phase of the principal portion of the W_1 motion with that of the principal maximum of the W_2, we find :—

TABLE XLVIII. Propagation Velocity of the Maximum Phase in the W_2 Motion, calculated by "Difference Method."

Station.	Epicentral Distance $=x$	Time Difference $=t_5'-t_5$	Velocity $v_5' = \frac{360° - 2x}{t_5'-t_5}$
San Fernando.	66° 47′	$2^{h}\ 03^{m}\ 01^{s}$	3.42 km per sec.
Cape Town.	85 46	1 32 06	3.78
Baltimore.	104 47	1 20 24	3.47
Wellington.	115 45	0 29 24	(?)
Alipore.	13 42	3 16 12	3.14
Colaba.	13 28	3 20 21	3.09
Mean.	....	....	**3.38**

Thus the values of the v_5' calculated by the "difference method" are, place for place, nearly identical with those calculated by the "direct method." According to the above table, the average velocity is

$$v_5' = 3.38 \text{ km per sec.},$$

which is practically identical with that obtained from Table XLVII.

143. ***Comparison of the Velocities of W_2 for different sets of stations.*** The results respecting the velocities of the W_2 motion stated in the two preceding §§ may be summarized as in the following table.

TABLE XLIX. Comparison of the Velocities of the W_2 Motion, calculated by "Direct Method."

(*A*) Tokyo, Osaka, Tadotsu, Querce, Potsdam, Göttingen, Birmingham. (*B*) Washington, Cheltenham, Tacubaya.		Phase of Motion.	British Stations.	San Fernando, Cape Town, Baltimore, Wellington, Alipore, Colaba.
Phase of Motion.	Velocity.		Velocity.	Velocity.
3rd Ph., P.P., W_1	km/sec. $v_5 = \begin{cases} 3.11 \ (A) \\ 3.25 \ (B) \end{cases}$	3rd Ph., P.P., W_1	km/sec. $v_5 = 3.26$	km/sec. —

(*A*) Tokyo, Osaka, Tadotsu, Querce, Potsdam, Göttingen, Birmingham. (*B*) Washington, Cheltenham, Tacubaya.		Phase of Motion.	British Stations.	San Fernando, Cape Town, Baltimore, Wellington, Alipore, Colaba.
Phase of Motion.	Velocity.		Velocity.	Velocity.
Commencement, W_2	km/sec. 5.02 (*A*) 4.96 (*B*)	Commencement, W_2	4.14	km/sec. ——
1st Max., W_2	3.70 (*A*) 3.83 (*B*)	1st Max., W_2	3.71	——
2nd Max., W_2	$v_5'=3.38$ (*A*)	Principal Max., W_2	$v_5'=3.32$	$v_5'=3.33$
——	——	Next Max., W_2	3.14	——

From the above table, it will be seen amongst others that the principal maximum of W_2 in the Milne photograms corresponded to the 2nd (greatest) maximum in the mechanical records. The average values of the velocities v'_5 and v_5, calculated both according to the "direct" and "difference" methods, are as follows:—

TABLE L. Average Values of the Velocities of W_1 and W_2 Waves.

Method of calculation.	v_5=Velocity of 3rd Ph, Principal Portion, W_1.	v'_5=Velocity of 2nd or Principal Max., W_2.
Direct Method.	3.21$^{\text{km/sec.}}$	3.34$^{\text{km sec.}}$
Difference „	3.28 (§ 115)	3.39

The agreement between v_5 and v'_5 is very close, and we may conclude that the principal maximum in the W_2 motion approximately corresponds to the commencement of the 3rd phase of the principal portion. We have further:—

Velocity of the commencement of $W_2 = 5.0$ km/sec.
„ „ 1st maximum „ $= 3.75$ „

144. *Amplitude and Period of Vibration in W_2 Motion.* Table LI gives the elements of motion during the successive epochs of W_2 at each of the 10 stations, as follows :—

(*A*) Japanese Stations.......	Tokyo (EW). „ (NS). „ (Vertical). Osaka (EW). Tadotsu (EW).
(*B*) American & Mexican Stations.	Cheltenham (NS). „ (EW). Tacubaya (NS). „ (EW). Washington (NS).
(*C*) European Stations.......	Querce (NW-SE). Birmingham (EW). Potsdam (EW). „ (NS). Göttingen.

TABLE LI. Observation
(*A*) Japanese

Phase of Motion.	Tokyo. EW Component.			Tokyo. NS Component.		
	Duration.	T	$2a$	Duration.	T	$2a$
	m s	sec.	mm	m s	sec.	mm
Commencement of W_2..	—	—	—	2 15	45.0 11.9	0.1
	—	—	—	16 04	19.1 12.6	—
	9 23	30.0	0.06	19 21	—	—
				4 00	—	—
1st Maximum.........	6 28	24.3	0.13	2 45	25.4	0.1
	2 38	22.1	Small	8 28	20.7	—
2nd Maximum........	7 05	19.4	0.19	4 14	19.5	0.12
Subsequent Phases....	43 09	17.2	Small	5 13	19.5	Small
				8 42	19.0	0.09
				1 58	17.4	Small
				2 57	16.9	Small
				6 56	29.5	0.05
				4 46	20.8	Small
				39 36	26.0	,,

of the W_2 Motion.
Stations.

Tokyo. Vertical Compt.			Osaka. EW Component.			Tadotsu. EW Component.		
Duration.	T	$2a$	Duration.	T	$2a$	Duration.	T	$2a$
m s	sec.	mm	m s	sec.	mm	m s	sec.	mm
—	—	—	—	—	—	—	—	—
—	—	—	1 20	—	—	—	—	—
—	—	—	5 26	25.1	Small	—	—	—
—	—	—	5 13	20.8	„	—	—	—
—	—	—	3 00	20.0	0.02	—	—	—
—	—	—	1 31	18.2	Small	—	—	—
			5 56	18.7	0.06	5 13	—	Small
4 09	—	Small	5 00	—	—	12 25	19.5	0.05
3 15	19.5	„						
—	—	—	—	—	—	—	—	—

(*B*) American and

Phase of Motion.	Cheltenham. NS Compt.			Cheltenham. EW Compt.		
	Duration.	*T*	2*a*	Duration.	*T*	2*a*
	m s	sec.	mm.	m s	sec.	mm.
Commencement of W_2	—	—	—	—	—	—
	—	—	—	—	—	—
1st Maximum.	5 19	29.0	0.06	—	—	—
	1 46	23.6	0.06	—	—	—
2nd Maximum.	4 46	22.0	0.19	4 36	19.7	0.28
	10 10	18.5	0.06	2 05 4 20	— 17.4	Small. 0.10

(*C*) European

Phase of Motion.	Querce. NW-SE Compt.			Birm'gham. EW Compt.		
	m s	sec.	mm.	m s	sec.	mm.
Commencement of W_2	—	—	—	16 55	25.2	Small.
	5 24	15.1	0.12			
	3 46	—	Small.			
1st Maximum.	8 12	—	”	10 21	18.3	”
	6 38	18.1	0.12			
2nd Maximum.	4 16	—	Small.			
	4 13	—	”	1 10	17.5	”
	4 31	18.0	0.14			
	4 36	18.0	0.27			
	4 48	—	Small.			
	6 16	—	”			

Mexican Stations.

Tacubaya. NS Compt.			Tacubaya. EW Compt.			Washington. NS Compt.		
Duration.	T	$2a$	Duration.	T	$2a$	Duration.	T	$2a$
m s	sec.	mm.	m s	s c.	mm.	m s	sec.	mm.
—	—	—	—	—	—	10 00	16.5	Small.
—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	5 30	27.0	—
—	—	—	—	—	—	—	—	—
5 00	19.4	0.48	20 35	18.0	0.10	13 00	21.9	—
15 30	16.0	0.15				5 50	13.5	—

Stations.

Potsdam. EW Compt.			Potsdam. NS Compt.			Göttingen.		
m s	sec.	mm.	m s	sec.	mm.	m s	sec.	mm.
5 00	20.0	0.13				—	25.0	—
4 44	24.4	0.18						
34 20	—	—	20 20	17.8	0.08	—	20.0	0.07

The following remarks on the amplitude and period of the W_2 motion are based on the preceding table.

Amplitude. The greatest $2a$ of 0.48 mm occurred in the NS component at Tacubaya, the dependence of the W_2 amplitude on the epicentral *major-arc* distance being as follows:—

Tacubaya........	231° 21′	$2a=0.48^{mm}$	(NS Compt.)
Cheltenham......	254 38	0.28	(EW „)
Querce..........	308 06	0.27	(NW-SE „)
Tokyo..........	308 34	0.19	(EW „)

Each of the above maximum movements had period varying between 18.0 and 19.7 sec., with the mean value of 19.1 sec. The 2nd maximum was always greater than the 1st maximum, the mean ratio being nearly that of 2 : 1.

In the NS component diagram obtained at Tacubaya, the W_2 motion was very well marked, the amplitude recorded being actually greater than that of the W_1 motion, or the earthquake proper. As Tacubaya is situated nearly in the meridian passing through the earthquake origin, the NS component motion corresponds to the *longitudinal wave*, the EW component motion corresponding to the *transverse wave*. (See also § 7.) The max. $2a$'s of the W_2 motion in these two directions were in the ratio of 4.8 : 1.

Period. At the commencement of the NS component of W_2 at Tokyo there were some slow vibrations of $T=45$ sec. The periods occurring in the 1st maximum group and the epoch immediately preceding it, which together form the 2nd phase of the principal portion, were as follows:—

30.0 sec.	27.0 sec.	22.1 sec.	16.5 sec.	12.6 sec.
29.0	25.4	20.8	15.1	11.9
Mean. **29.5**	25.2	20.7	*Mean*, **15.8**	*Mean*, **12.3**
(Max. $2a$=0.06 mm)	25.1	20.0	(Max. $2a$=0.12 mm)	(Max. $2a$=Small).
	25.0	20.0		
	24.4	19.5		
	24.3	19.1		
	23.6	18.3		
	Mean, **25.0**	18.2		
	(Max. $2a$=0.18 mm)	18.1		
		Mean, **19.7**		
		(Max. $2a$=0.13 mm)		

Thus in the 2nd phase of the principal portion there were 5 sorts of period, whose average values were respectively 29.5; 25.0; 19.7; 15.8; and 12.3 sec.; the $2a$ enclosed in brackets giving the absolutely maximum (single component) motion for each kind of the periods. It will be observed that the vibrations of periods 25.0 and 19.7 sec. were larger and of much more frequent occurrence than those of other periods.

The periods occurring in the 2nd maximum group and the subsequent epochs, which together formed the 3rd phase of the W_2 principal portion, were as follows:—

29.5 sec.	22.0 sec.	18.7 sec.	13.5 sec.
(Max. $2a$=0.05 mm)	21.9	18.5	(Small.)
	20.8	18.0	
	20.0	18.0	
	20.0	18.0	
	19.7	17.8	
	19.5	17.5	
	19.5	17.4	
	19.5	17.4	
	19.4	17.2	
	19.4	16.9	
	19.0	16.0	
		Mean, **18.9** sec.	
		(Max. $2a$=0.48 mm)	

Thus in the phase under consideration, the period varied, with two exceptions, between 16.0 and 22.0 sec., giving a mean value of 18.9 sec. The vibrations of this sort are evidently the same as those in the previous phase whose mean period was 19.7 sec.

Again, comparing together the three tables (*A*), (*B*), and (*C*), we see that on the whole slower vibrations occurred first, the approximate order of succession of the principal different periods being as follows :—(i) 45.0 ; (ii) 29.5 ; (iii) 25.0 ; (iv) 19.7—18.9 sec. This occurrence of periods in the descending order of magnitude (length) is a characteristic of the principal portion of the earthquake motion.

Average Periods. The mean values of the various periods of vibration in the W_2 motion recorded at the different stations are collected in the following table, those of more frequent occurrence being printed in thick characters.

TABLE LII. Average Values of the Periods in W_2 Motion.

	sec.	sec.	sec.	sec.	sec.	sec.	sec.
Tokyo.	**12.3**	—	**19.4**	—	**25.1**	**29.8**	45.0
Osaka.	—	—	**19.6**	—	25.1	—	—
Tadotsu.	—	—	19.5	—	—	—	—
Göttingen.	—	—	20.0	—	25.0	—	—
Potsdam.	—	17.2	20.0	—	24.4	—	—
Querce.	—	15.1	**18.0**	—	—	—	—
Birmingham.	—	17.5	**18.3**	—	25.2	—	—
Washington.	13.5	16.5	—	21.9	—	27.0	—
Cheltenham.	—	—	**18.6**	**22.8**	—	29.0	—
Tacubaya.	—	—	**18.2**	—	—	—	—
Mean.	**12.7**	16.6	**19.1**	**22.5**	**25.0**	**28.9**	45.0

Thus it will be observed that the period most frequently occurring is 19.1 sec., being almost universally indicated at the different places. The 2nd maximum group of the W_2 motion, in which the above-mentioned period predominated, may be taken as corresponding to the 3rd phase of the principal portion of the W_1 motion, or earthquake proper.

REPETITION OF THE EARTHQUAKE MOTION FIRST PROPAGATED ALONG THE MINOR ARC.

145. ***Observation of W_3 Motion.*** TABLE LIII gives the times of occurrence of the W_3 wave or the repetition of the earthquake motion first propagated along the minor arc, observed more or less clearly at the 7 stations of Tokyo, Osaka, Tadotsu, Cheltenham, Shide, Wellington, and Colaba.

TABLE LIII. Observation of W_3 Motion: Times of Occurrence.

Station.	Epicentral Distance $= x$.	W_1 Motion (Eqke. Proper)		Commencement of $W_3 = t_5$.''
		Time of occurrence $= t_1$	Commencement of 3rd Phase, Princ. Port. $= t_5$	
		h m s	h m s	h m s
Tokyo (EW).	51° 26′	0 59 08	1 22 26	4 24 08
Osaka (EW).	48 19	0 58 51	1 19 52	4 34 59
Tadotsu (EW).	47 02	0 58 49	1 18 52	4 24 35
Cheltenham (NS).	105 22	1 08 39	1 49 12	5 22 04
Shide.	58 52	1 01 00	1 22 42	4 34 45*
Wellington.	115 45	1 09 48	1 59 54	4 36 36
Colaba.	13 28	0 53 08	0 56 39‡	4 24 00

* Meaned from the records given by the two pendulums B and C.

‡ Commencement of the principal portion.

The propagation velocity of the W_3 motion may be calculated by the "direct method" according to the formula

$$\text{Velocity} = \frac{360^\circ + x}{t''_5 - t_0},$$

where t'' denotes the time of occurrence of W_3. We obtain the following results :—

TABLE LIV. Velocity of the W_3 Motion, calculated by "Direct Method."

Station.	Epicentral Distance. $=360^\circ+x$.	Time Difference $=t''-t_0$	Velocity. "Direct Method."
Tokyo.	411° 26′	$3^h\ 33^m\ 20^s$	3.57 km/sec.
Osaka.	408 19	3 45 11	3.36
Tadotsu.	407 02	3 34 47	3.61
Cheltenham.	465 22	4 32 16	3.17
Shide.	418 52	3 44 57	3.46
Wellington.	475 45	3 46 48	3.89
Colaba.	373 28	3 34 12	3.23
Mean	....	....	**3.40**

The identification of the W_3 motion was extremely difficult, and the results above obtained are to be regarded as, at the best, only gross approximations. The average value of the velocity is **3.40** km per sec.,* which is nearly equal to that of the 3rd phase of the principal portion of W_1. Assuming, therefore the W_3 motion to correspond to the 3rd phase of the principal portion, we obtain, from Table LIII:—

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* As will be seen from the value of $(t''-t_5)$ given below, the identification of W_3 for Wellington is probably not quite correct. The velocity for this station has therefore been excluded in deducing the average.

		h	m	s
Tokyo.	$t_5'' - t_5 =$	3	01	42
Osaka.		3	15	07
Tadotsu.		3	05	43
Cheltenham.		3	32	52
Shide.		3	12	05
Wellington.		2	36	42*
Colaba.		3	27	21
Mean		3	15	48

The mean time difference of **$3^h\ 15^m\ 48^s$**, deduced by excluding the value for Wellington (marked with an ***asterisk***), is the time interval taken by the earthquake motion in making one complete circuit round the earth and does not depend on the epicentral distance x. We have:—

$$\text{Velocity} = \frac{\text{Earth's Circumference}}{t_5'' - t_5} = \frac{360^\circ}{3^h 15^m 48^s} = 3.40 \text{ km/sec.}$$

(See also the *Publications*, No. 13).

Periods of Vibration. The periods of vibration occurring in the W_3 motion were as follows.

	sec.	sec.	sec.
Tokyo.	20.5	—	44.0
Osaka.	18.5	—	—
Tadotsu.	—	36.3	—
Cheltenham.	18.2	—	—
Mean.	**19.1**	36.3	44.0

The principal period of vibration in W_3 is the same as that occurring in the most active part of the W_2 motion.

GENERAL REMARKS ON THE PROPAGATION VELOCITIES.

146. ***Velocities calculated by " Direct Method."*** The mean values of the different velocities calculated by the " direct method " are as follows.

TABLE LV. Mean values of the Velocities.
" Direct Method."

Phase of motion.	Velocity.	Limits of Epicentral Distance.	Mean Distance.
	km/sec.		
1st Prel. Tremor.	v_1 =**10.52**	50° —121°	76°
2nd ,, ,,	v_2 = **5.63**	40 —115 45′	61 36′
1st Phase, Princ. Port.	v_3 = **4.07**	47 —128 47	70 52
3rd ,, , ,,	v_5 = **3.11**	39 27′—128 47	**Practically independent of the distance *x*.**
Commencement, W_2.	**5.0**		
1st Maximum, W_2.	v_5 = **3.75**		
Principal max., W_2.	v_5' = **3.34**		
W_3	v_5''= **3.40**		

The four velocities v_1, v_2, v_3, and v_5 are in the ratios of 100: 53.5 : 38.7 : 29.6. The velocity of the principal maximum of W_2 and that of W_3 are approximately equal to v_5. The 1st maximum of W_2 seems to correspond to the 2nd phase of the principal portion, and the earliest recorded commencement of the major arc propagation to some part of the 2nd preliminary tremor.

The average values of the velocities for the stations in Middle Europe and Japan are as follows:—

v_1=**10.38** km/sec. (22 stations, mean x=50° 24′)
v_2= **5.73** ,, (20 ,, , ,, =50 12)
v_3= **3.92** ,, (7 ,, , ,, =50 17)
v_5= **3.02** ,, (8 ,, , ,, =50 34)

These 4 velocities are in the ratios of 100 : 55 : 38 : 29.

147. *Velocities calculated by "Difference Method."* The mean values of the different velocities calculated by the "difference method" are as follows.

TABLE LVI. Mean Values of the Velocities.
"Difference Method."

Phase of motion.	Velocity.	Limits of Epicentral Distance.
1st Preliminary Tremor.	kms/sec. v_1 = **11.36**	27° 57′—121° 16′
2nd " "	v_2 = **6.46**	27 42 —128 47
1st Phase, Princ. Portion.	v_3 = **4.70**	39 27 —128 47
3rd " , " "	v_5 = **3.28**	39 27 —128 47
Principal Maximum, W_2.	v_5' = **3.39**	
W_3	v_5'' = **3.40**	

The 4 velocities v_1, v_2, v_3, and v_5 are in the ratios of 100 : 56.9 : 41.4 : 28.9; the mutual relations being nearly the same as in the cases of the velocities calculated by the "direct method." The agreement of the velocities of W_2 (principal max.) and W_3 with that of the 3rd phase of the principal portion is here closer than in the case of the "direct method" calculation.

Comparisons of the velocities calculated by "direct" and "difference" methods. Comparing the mean values of the different velocities calculated according to the "direct method" with those calculated according to the "difference method," as given in Tables LV and LVI, we obtain :—

$$\left\{\begin{array}{l}
v_1\left(\begin{smallmatrix}\text{Difference}\\ \text{Method}\end{smallmatrix}\right)-v_1\left(\begin{smallmatrix}\text{Direct}\\ \text{Method}\end{smallmatrix}\right)=0.84\text{ km/sec.}\\
v_2\,(\quad ,, \quad)-v_2\,(\quad ,, \quad)=0.83\\
v_3\,(\quad ,, \quad)-v_3\,(\quad ,, \quad)=0.63\\
v_5\,(\quad ,, \quad)-v_5\,(\quad ,, \quad)=0.17\\
v_5'\,(\quad ,, \quad)-v_5'\,(\quad ,, \quad)=0.05\\
v_5''\,(\quad ,, \quad)-v_5''\,(\quad ,, \quad)=0.00
\end{array}\right.$$

Thus it will be seen that the velocities v_1, v_2, and v_3, calculated by the "difference method" were each greater 0.63 to 0.84 km per sec., than those calculated by the "direct method." The discrepancy is, however, very small or *nil* for the velocities v_5, v_5', and v_5''. This fact seems to give support to the view that the vibrations composing the 1st and 2nd preliminary tremors, as well as the earlier part of the principal portion, are propagated some considerable depth below the surface, the length of the actual path for each of these sets of waves materially differing from that of the arcual epicentral distance.

148. ***Mutual Relations of the different Velocities.*** Assuming the durations of the first 7 successive sections of the earthquake motion to be, as stated in § 8, in the ratios of 100 : 95 : 79 (1st and 2nd phases of principal portion taken together) : 91 : 95 : 95, we have the following general relations among the different velocities*:—

$$\begin{array}{ll}
\dfrac{1}{v_2}=\dfrac{1}{v_1}+\dfrac{y_1}{x}; & \dfrac{1}{v_6}=\dfrac{1}{v_5}+\dfrac{91\,y_1}{100\,x};\\[2ex]
\dfrac{1}{v_3}=\dfrac{1}{v_2}+\dfrac{95\,y_1}{100\,x}; & \dfrac{1}{v_7}=\dfrac{1}{v_6}+\dfrac{95\,y_1}{100\,x};\\[2ex]
\dfrac{1}{v_5}=\dfrac{1}{v_3}+\dfrac{79\,y_1}{100\,x}; & \dfrac{1}{v_8}=\dfrac{1}{v_7}+\dfrac{95\,y_1}{100\,x};
\end{array}$$

x being the epicentral distance of a given station, and y_1 the duration of the 1st preliminary tremor at the latter. The quotient y_1 / x is to be determined from some of the equations (1) to (4) in § 121, and the equation (7) in § 123. As an example, let us apply the above relations to the velocities of the Kangra earthquake calculated by the "direct method" for the stations in Middle Europe and Japan, (§ 146); the mean value of the x being 50° 22′, and the quantity y_1 / x being given by equation (1) of § 121. Assuming $v_1 = 10.38$ km/sec., we have :—

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* See the *Publications*, No. 5 and No. 13.

Actual Value.	*Calculated Value.*
$v_1 = 10.38$ km/sec.	10.38 km/sec.
$v_2 = 5.73$	5.6
$v_3 = 3.92$	3.9
$v_5 = 3.02$	3.1

The agreement between the actual and calculated values is fairly good.

Ratio of $v_1 : v_2$. The ratios of the 4 velocities v_1, v_2, v_3, and v_5, are, according to the two preceding §§, as follows :—

(i) "Direct Method."......100 : 53.5 : 38.7 : 29.6
(ii) "Difference Method."..100 : 56.9 : 41.4 : 28.9
Mean............. **100 : 55.2 : 40.1 : 29.3**

Thus, amongst others, the mean ratio of $v_1 : v_2$ is 100 : 55.2. Now, the equation* for determining the time (t_0) of earthquake occurrence at the origin, from the duration (y_1) of the 1st preliminary tremor, is

$$t_0 = t_1 - \frac{y_1}{\frac{v_1}{v_2} - 1} \dots\dots\dots\dots (1)$$

Putting the mean ratio of $v_1 : v_2$ above obtained, the equation becomes :—

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* The *Bulletin of the Imperial Earthquake Investigation Committee*, Vol. I, No. 1.

$$t_0=t_1-1.232\ y_1 \ldots\ldots\ldots(2)$$

For the purpose of practical application, however, it seems better to adopt the ratio of $v_1 : v_2$ obtained by the "direct method"; the formula then becomes

$$t_0=t_1-1.151\ y_1 \ldots\ldots\ldots(3)$$

Equation (3) does not much differ from one previously given.

149. ***Remarks on the Methods of Velocity Calculation.*** In all the velocity calculations by the "direct method" given in the preceding Chapters, the times of occurrence of the different phases of the earthquake motion at a given station have been compared with the time (t_0) at the origin of disturbance. This is equivalent to assuming that at the latter there existed no preliminary tremor; in other words, that the various sets of vibrations composing the seismic motion were generated simultaneously at the centre. I believe this supposition is generally legitimate, although there is possibility, especially in cases of large earthquakes, of slight premonitary shakings apart from the usual preliminary tremors.

Chapter X. Miscellaneous Remarks.

150. ***Notes on the Tokyo Observations.*** The following remarks on the Tokyo observations are based on the analysis of the seismograms of the Kangra earthquake given in §§ 13 to 21.

151. *Small movements of Sensible or Macro-seismic Character.* The Hitotsubashi diagram furnished by a horizontal pendulum of 8 times magnification indicated in the 1st preliminary tremor small vibrations, whose average period was 0.71 sec. These movements were evidently of the character of macro-seismic or sensible motion, their period being nearly equal to that most frequently occurring in ordinary earthquake shocks observed at Hitotsubashi.* The occurrence in distant earthquakes of quick vibrations, whose period is about 1 sec., is not very rare † From the observations like the above we may conclude:

(i) That *a great earthquake disturbance may give rise to small vibrations of macro-seismic character at a considerably distant place, especially when the soil at the latter is soft.* It is a movement of this sort which starts the electric contact-maker of an ordinary Ewing or Gray-Milne seismograph at a far-off station; those large vibrations in the 2nd preliminary tremor or the different phases of the principal portion are quite inadequate to affect a macro-seismograph on account of the length of the period, their acceleration of motion of the earth's particle being a very small quantity.

(ii) That *the principal period of the macro-seismic vibration at Hitotsubashi is practically constant and independent of the earthquake cause or of the epicentral distance.* This inference, which probably holds good for any other place where the ground is soft, may be accounted for by assuming that the earthquake vibrations at a place are essentially composed of the proper oscillations of the ground characteristic to the region in question;‡ well defined vibrations at the commencement of the different phases of the motion being excepted.

152. *Pulsatory Oscillations.* Both before and after the Kangra earthquake there existed very small pulsatory oscillations, which were clearly recorded by the tromometers, and which belonged to the Q_1 class motion,* their average period being 4.1 sec. By the way, it may be remarked that the period of these pulsatory oscillations was identical at the University Compound (Hongo) and at the Central Meteorological Observatory, in spite of a mutual distance of 3 km, and of an entire difference in the nature of the grounds, between the two places.

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* See the *Publications*, No. 11 and No. 13.

† The *Publications*, No. 13.

‡ See the *Publications*, No. 11 and No. 13.

Turning our attention to the P_1 motion, we find from §§ 14 to 20, that the records furnished by the different instruments were as follows :—

			T	Max. $2a$
EWCOMPONENT.	§ (14) :	1st Prel. Tremor,....	4.6 sec. ;	0.20 mm
	„ (20) :	„	4.4	0.25
	„ (21) :	„	4.4	0.17
	„ (18) :	„	4.6	0.35
	„ (20) :	2nd Prel. Tremor.....	4.8	0.21
		Mean..........	**4.6** sec.	**0.24** mm
NS COMPONENT	:	1st Prel. Tremor,....	5.2 „	0.14 „
VERTICAL COMPT	:	„ „ ,	4.2	0.71 (?)

Comparing, for the EW component, the pulsatory oscillation (Q_1) with the earthquake vibration (P_1), we see that the amplitude of the latter was some 20 times that of the former ; the periods of the two sets of motion being, however, nearly equal to one another. This result seems to give support to the theory advanced by me some years ago that the pulsatory oscillations (Q_1 and Q_2) and the earthquake vibrations (P_1 and P_2) are essentially alike in nature, and that the latter consist in the amplification of the former, which always exist more or less at, and characterize, a given district.† For the sake of reference, I give next the periods of the pulsatory oscillations on Mount Tsukuba (in the province of Hitachi, Japan), at Ishinomaki (province of Rikuzen), Osaka, and Taito (Formosa):

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* See the *Publications*, No. 13.

† See the *Publications*, No. 13.

(i)	Mount Tsukuba* (Province of Hitachi, Japan).	Q_1:	T=about 4 sec.
(ii)	Ishinomaki.	Q_1:	$T=5.2$ sec., $2a=0.05$ mm.
(iii)	Taito (Formosa).	Q_1:	$T=5.6$ „ , $2a=0.2$ mm $T=4.7$ „ , $2a<0.2$ mm.
(iv)	Osaka.	Q_1:	$T=5.0$ sec.

The pulsatory oscillation indicated on the Batavia photogram (§ 47) had a period of 7.6 sec. and may correspond to Q_2.

153. *On the Comparison of Diagrams furnished by different instruments; existence of P_2 vibrations in the 2nd Preliminary Tremor and the Principal Portion.*

As will be seen from § § 14 and 20, the diagram given by the long-period horizontal pendulum is materially different from that given by the tromometer. Thus, the former diagram shows, in the 2nd preliminary tremor most prominently 4 sets of slow vibrations of T respectively$=49.7$ sec., 37.7 sec., 86.0 sec., and 26.5 sec.; the P_1 and P_2 vibrations being altogether absent or only insignificantly shown. On the other hand, the 2nd preliminary tremor in the tromometer diagram is entirely made up of 3 sets of comparatively quick movements, namely, P_1, P_2, and $P_{2,3}$ vibrations, Again, the long-period pendulum record indicated, in the 1st and 2nd phases of the principal portion, prominent vibrations of T of 27.6 to 59.0 sec.; $P_{2,3}$ vibrations being only slightly shown. In the corresponding part of the tromometer record, however, P_2 vibrations were indicated nearly to the same extent as other slower movements, whose period varied between 16.8 sec. and about 53 sec.

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* The observation made with a horizontal pendulum tromometer by His Imperial Highness Prince Yamashina at his Observatory on Mount Tsukuba has proved that the pulsatory oscillation exists, though slightly, also on solid mountain tops.

The principal cause of the great dissimilarity between the records furnished by the two instruments was evidently in the difference in the lengths of the periods of natural oscillation of the two pendulums.*

The real amplitude of the slow vibrations in the 2nd preliminary tremor and the principal portion seems, in great earthquakes, to be considerable and much greater than is shown in most seismograms; the friction between the different parts of the seismograph reducing, even when the *steady mass* has a long oscillation period, the *recorded* range of such a motion more or less.

One notable fact demonstrated by the tromometer record is that the P_2 vibrations were not confined to the 1st preliminary tremor, but also occurred prominently in the 2nd preliminary tremor and in the 1st and 2nd phases of the principal portion. It is highly probable that the P_2 vibrations exist throughout the principal portion of every large earthquake motion. (See also § 126.)

The question of the existence of P_2 vibrations in the principal portion is very important in connection with the discussion of the different periods occurring in the earthquake motion. As I have pointed out in the *Publications*, No. 13,‡ the principal period of vibration occurring in the *preliminary tremors* and the *end portion* is P_2 (some times P_1), and it would be strange, if similar movements did not occur in the intermediate phases, namely, the *principal portion*; it being quite natural to assume some existence throughout the earthquake motion of the P_1 and P_2 vibrations, which are identical to the proper Q_1 and Q_2 oscillations of the ground.

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* See the *Publications*, No. 23.

‡ Published in 1901.

154. *Direction of Motion.* Confining our attention to the EW component, we see, from the analysis of the record given by the long-period instrument (§ 14), that the 1st displacement of the initial slow vibration of each of the two preliminary tremors was directed towards *W*; the 1st motion of the initial (P_1) vibration of the 1st preliminary tremor being, according to the tromometer record (§ 20), also directed towards *W*. Similar directional tendency of motion was shown more clearly in the 3rd phase of the principal portion recorded by the latter instrument, where there were a series of maximum groups, of which 4 well defined ones have been described in § 20. The amplitudes of the successive displacements of vibrations composing one of these groups were, on the average, in the following relative ratios :—

1st displ.	2nd displ.	3rd displ.	4th displ.	5th displ.	6th displ.
(E)	(W)	(E)	(W)	(E)	(W)
1.00	1.84	3.31	6.22	6.90	5.60

It will be thus seen that the 1st, 2nd, and 3rd displacements, were directed towards E, W, and E, respectively; it being the 4th and westward motion which constitutes the first and sudden large displacement.

In the NS component diagram (§ 15), the 1st displacement of the well-defined slow vibration at the commencement of the 1st preliminary tremor was directed towards N; the very initial motion of quick movements mixed with the above being also directed towards N.

155. ***Similarity with the diagrams of the Alaska earthquakes.*** The EW component Tokyo diagram of the Kangra earthquake (Pl. I, the *Publications*, No. 23) is on the whole somewhat similar to those of the Alaska earthquakes of 1899 and

1900*; the movements at the commencement of the 2nd preliminary tremor being specially alike each other. This is evidently the result due to a sort of symmetry of the positions of the origins of the two sets of earthquakes with respect to the meridian (or prime vertical) of Tokyo; the positions of the centres in question relative to the latter place being as follows:—

	Epicentral Distance of Tokyo.	Azimuth of Eqke. Origin.
Kangra Eqke.	51° 26′	W 75° 05′ 36″ (from N)
Alaska Eqkes.	55° ca.	E 40° ca.

156. *Time Difference between Tokyo and Osaka.* The times of commencement of the successive phases of motion at Tokyo and Osaka were as follows:—

TABLE LVII. Time Difference between Tokyo and Osaka.

	Phase of motion. (Commencement)	Tokyo.	Ōsaka.	Time Difference. (Tokyo—Osaka.)
		h m s	h m s	sec.
(i)	1st Prel. Tremor.	0 59 08	0 58 51	+17
(ii)	2nd „ „	1 06 46	1 06 03	43
(iii)	1st Phase, Princ. Portion.	1 14 24	1 13 15	69
(iv)	3rd „ , „	1 22 34	1 20 09	145
(v)	4th „ , „	1 33 49	1 30 05	224
(vi)	5th „ , „	1 42 04	1 38 05	239
(vii)	Max. Mot. in W_2.	3 39 07	3 40 56	−109

The arcual epicentral distances of Tokyo and Osaka are 51° 26′ and 48 19′ respectively, and consequently the time differences between these two places (Tokyo—Osaka) were positive for the different phases of W_1 or the earthquake proper, but negative for the W_2 motion. It is difficult to determine exactly the instants of commencement of some of the different phases of motion, and the above time differences are only rough values, with the exception of two well defined cases of the 2nd and the last; which two relate respectively to the commencements of the 2nd preliminary tremor and the maximum vibration in the W_2 motion. Calculating from these two cases the transit velocities, we obtain the following approximate results :—

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* See Pls. VII and VIII of the *Publications*, No. 5, and Pl. XXXVI of the *Publications*, No. 21.

$$\left\{\begin{aligned} v_2 &= \frac{51^\circ\,26'-48^\circ\,19'}{43^{\text{sec.}}} = 8.0 \text{ km/sec.}; \\ v'_5 &= \frac{51^\circ\,26'-48^\circ\,19'}{109^{\text{sec}}} = 3.18 \quad ,, \quad . \end{aligned}\right.$$

(See also Chapter IX.)

157. Comparison of individual vibrations in the Tokyo and Osaka Seismograms. Some of the individual vibrations in the 1st and 2nd preliminary tremors can be identified with fair accuracy in the Tokyo and Osaka EW component diagrams; the times of occurrence of the corresponding movements in the two records, denoted by similar letters, *a*, *b*, *c*, *d*,. . . . *s*, *t*, *u*, being as in the following table. (See Pls. I and VI, the *Publications*, No. 23.)

TABLE LVIII. Comparison of the Different Vibrations in the Tokyo and Osaka EW Diagrams.

Vibration.	Tokyo.	Ōsaka.	Time Difference. (Tokyo-Osaka).
	h m s	h m s	sec.
a	0 59 08	0 58 51	17
b	0 59 36	0 59 16	20
c	1 00 05	0 59 40	25

Vibration.		Tokyo.	Ōsaka.	Time Difference. (Tokyo-Ōsaka).
		h m s	h m s	sec.
1st Prel. Tremor.	*d*	1 00 28	0 59 56	32
	e	1 01 24	1 01 03	21
	f	1 01 36	1 01 12	24
	g	1 02 23	1 02 02	21
	h	1 06 38	1 06 03	35
2nd Prel. Tremor.	*i*	1 06 46	1 06 08	38
	j	1 07 05	1 06 18	47
	k	1 07 23	1 06 35	48
	l	1 07 55	1 06 50	65
	m	1 08 53	1 07 58	55
	n	1 09 49	1 08 49	60
	o	1 10 48	1 09 58	50
	p	1 11 07	1 10 19	48
	q	1 11 45	1 10 42	63
	r	1 12 34	1 11 25	69
	s	1 13 07	1 11 53	74
	t	1 13 40	1 12 23	77
	u	1 14 24	1 13 15	69

The identifications given in the above table indicate, on the whole, a gradual separation of the successive vibrations at the rate of about 3.93 sec. for 1 minute of the duration.

158. ***Kew, Paisley, and San Fernando Records.*** Some of the maximum movements may be identified in the seismograms at San Fernando, Kew and Paisley; these are marked by the letters *a*, *b*....*m*, *n*. But the times of occurrence of these maxima at the above-mentioned 3 stations are, as given in the following table, not perfectly in accordance to the respective epicentral distances, due probably to an inaccuracy in the identifications. We can see, however, from examples like these, that the teleseismograms obtained at neighbouring places ought to be nearly identical, if not much interfered by the proper instrumental oscillations.

Max.	San Fernando.	Paisley.	Kew.	Max.	San Fernando.	Paisley.	Kew.
	h m	h m	h m		h m	h m	h m
a_1	1 16.0	1 13.2	—	*g*	1 51.7	1 48.6	1 45.7
a'	1 20.8	1 16.3	—	*h*	1 57.8	1 54.6	1 —
a	1 29.0	1 26.7	1 25.4	*i*	2 1.5	1 59.0	1 53.0
b'	1 31.7	1 29.0	1 27.3	*j*	2 7.0	2 5.8	1 56.5
b	1 33.8	1 31.4	1 28.9	*k*	2 14.5	2 12.8	2 7.6
c	1 36.7	1 34.4	1 32.6	*l*	2 20.4	2 17.9	2 13.7
d	1 39.0	1 36.4	1 35.5	*m*	2 27.6	2 30.4	2 22.0
e	1 42.5	1 39.8	1 37.7	*n*	2 35.7	2 38.5	2 31.0
f	1 45.5	1 43.9	1 40.4				

159. ***Vibrations of Short Periods.*** The periods shorter than P_1 observed at some of the different stations were as follows:—

(i) Hitotsubashi (Tokyo): $T=0.71$ sec.
(ii) Hongō „ : „ $=2.2$ „
(iii) Taihoku : „ $=1.07$ „ ; $T=2.1$ sec.
(iv) Batavia : „ $=1.4$ „
(v) Manila : „ $=2.6$ „ (pendulum oscillation.)
(vi) Göttingen : „ $=2.2$ „
(vii) Upsala : „ $=2.5$ „

The vibrations corresponding to these periods were always very small. As already stated in § 150, (i) is the same as the period of the motion on the occasion of ordinary shocks observed in the low soft part of Tokyo. The periods of 1.07 sec. at Taihoku (iii), and of 1.4 sec. at Batavia (iv), also characterize the movements of macroseimic nature. The semi-macroseismic periods observed at Hongō (ii), Taihoku (iii), Göttingen (vi), and Upsala (vii), varied between 2.1 and 2.5 sec., giving the average value of **2¼** sec. This is approximately equivalent to $\frac{1}{2}P_1$.

160. ***Durations of the Successive Sections of the Earthquake Motion.*** Let the durations of the 1st and 2nd preliminary tremors, and the 1st, 2nd, 3rd, and 4th phases of the principal portion be respectively denoted by y_1, y_2, $y_{3,4}$, y_5, and y_6; the 1st and 2nd phases of the latter portion being taken together. The values of the y's observed at the 15 different stations on the occasion of the Kangra earthquake are given in Table LIX; the stations being divided into two groups (I) and (II), according to their epicentral distances. An *asterisk* suffixed to the name of a station signifies that the respective durations have been deduced by taking the means from more than one seismogram.

TABLE LIX. Durations of the Successive Sections of the Earthquake Motion.

	Station.	1st Prel. Tremor. (y_1)	2nd Prel. Tremor. (y_2)	1st & 2nd Ph., Princ. Port. ($y_{3,4}$)	3rd Phase, Princ. Port. (y_5)	4th Phase, Princ. Port. (y_6)
	Tokyo.*	$7^{\mathrm{m}}\,17^{\mathrm{s}}$	$7^{\mathrm{m}}\,42^{\mathrm{s}}$	$7^{\mathrm{m}}\,19^{\mathrm{s}}$	$8^{\mathrm{m}}\,50^{\mathrm{s}}$	$^{\mathrm{m}}$ — $^{\mathrm{s}}$
	Osaka.	7 12	6 55	6 54	9 56	8 00
	Tadotsu.	7 00	7 42	5 21	6 30	6 00
	Taihoku.	6 06	5 25	4 35	5 30	—
	Taichu.	6 14	5 10	4 50	5 40	—
I	Birmingham.	8 21	7 37	8 49	9 30	6 21

	Station.	1st Prel. Tremor. (y_1)	2nd Prel. Tremor. (y_2)	1st & 2nd Ph., Princ. Port. ($y_{3,4}$)	3rd Phase, Princ. Port. (y_5)	4th Phase, Princ. Port. (y_6)
	Quarto-Castello, Querce, Ximeniano.	$7^{\mathrm{m}}\ 15^{\mathrm{s}}$	$(15^{\mathrm{m}}\ 09^{\mathrm{s}})$		$8^{\mathrm{m}}\ 15^{\mathrm{s}}$	—
	Göttingen.	7 17	$7^{\mathrm{m}}\ 40^{\mathrm{s}}$	$6^{\mathrm{m}}\ 35^{\mathrm{s}}$	5 55	5 35
	Leipzig.*	7 06	7 37	6 28	7 45	5 23
	Manila.	6 38	5 10	6 10	—	—
	Mean.	**7 03**	**6 56**	**6 26**	**7 41**	**6 07**
II	Washington.	15 02	12 09	12 41	22 50	—
	Cheltenham.*	14 44	12 15	14 39	11 31	11 20
	Tacubaya.	16 38	15 42	18 04	14 52	—
	Mean.	**15 17**	**13 05**	**15 46**	**15 11**	**11 20**

Thus it will be seen that the durations of the successive sections of the earthquake motion are, for each group of the stations, roughly equal to one another. The relative durations expressed in percentage numbers are given in the following table; the means deduced from the two groups (I) and (II), supposing their weights to be 2 : 1, being $y_1=100$, $y_2=94$, $y_{3,4}=95$, $y_5=106$, $y_6=83$.

TABLE LX. Relative Durations of the Successive Sections of the Teleseismic Motion.

Group.	y_1	y_2	$y_{3,4}$	y_5	y_6
I.	100	98	91	109	87
II.	100	86	103	99	74
Mean.	**100**	**94**	**95**	**106**	**83**
Table III, § 8.	100	95	79	91	95
General average.	**100**	**95**	**87**	**99**	**89**

For the sake of reference, I have also given in the above table the relative durations in question based on the previous observations made in Tokyo (§ 8). The general average values obtained by combining these with the means of the two groups (I) and (II) are as follows: $\boldsymbol{y_1=100}$, $\boldsymbol{y_2=95}$, $\boldsymbol{y_{3,4}=87}$, $\boldsymbol{y_5=99}$, $\boldsymbol{y_6=89}$. Table III (§ 8) gives the durations for the two more succeeding sections.

161. ***Wave-length of the Earthquake Motion.*** The wave-length (L) of the quickest and slowest teleseimic vibrations, whose periods are respectively P_1 and P_{19} and which occur in the 1st and 2nd preliminary tremors, are as follows:—

1st Prel. Tremor.......$L=P_1\times v_1=4.3\times 11.36=$ 49 km;
2nd „ „ ....$L=P_{19}\times v_2=86\times 6.41=556$ „ .

For the predominating vibrations in the 3rd phase of the principal portion, we have:—

$$L=P_5\times v_2=20.4\times 3.28=67 \text{ km.}$$

Thus it seems that the vibrations composing the teleseismic motion have each a long wave-length, ranging from about 50 km to over 500 km. Hence it is to be concluded that such earthquake motion does not vary according to the contour or nature of the ground within a limited area. On many occasions, I have obtained similar diagrams with the horizontal pendulums of different constructions at Hongō and Hitotsubashi, although at the former place the ground is high and hard, while at the latter it is low and very soft. It is probable that, had the instruments at Tokyo and Osaka been exactly identical in construction and adjustments, the diagrams of the Kangra earthquake at these two places would have been almost perfectly similar to each other. Notwithstanding the differences in the instruments, the seismograms at Tokyo and Osaka were so far alike, that the individual corresponding vibrations have in many cases, been identified. Conversely, it many be supposed that earthquakes originating at neighbouring centres would give, in general, similar diagrams at a given observing station. This has been verified in the cases of many teleseismic, as well as, macroseismic, or sensible earthquake motion observed in Tokyo.*

Quick Vibrations. Small quick vibrations of macroseismic nature occurring in the teleseismic disturbance seem, unlike the slow movements, to depend on the nature of the ground, and are probably to be regarded as the secondary effect of the microseismic or pulsatory movements.

162. ***Nature of the Two Preliminary Tremors.*** It is generally recognized that the 1st and 2nd preliminary tremors of the *telescismic motion* belong to the "longitudinal" and the "transverse" waves respectively. It is, however, not clear why the transverse vibration is in these cases always much greater than the longitudinal. The diagrams of the Kangra earthquake also indicate, in general, the same relation of the two preliminary tremors.

(i) *Mexico and America.* According to Table II (§ 8), Tacubaya is almost to the due north of the origin, and from the seismograms (Pl. X, the *Publications*, No. 23) we see that in the NS or longitudinal component, the vibrations in the 1st preliminary tremor was more distinct than in the EW or transverse component. The movements of the NS component were, however, less prominent than those of the EW, in the 2nd preliminary tremor and the 1st and 2nd phases of the principal portion; on the contrary, the NS component being much larger than the EW in the 3rd and 4th phases of principal portion and in the W_2 motion.

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* See the *Publications*, No. 21.

The Cheltenham records do not markedly indicate the directional peculiarity, except that the 3rd phase of the principal portion is much greater in the NS (longitudinal) component than in the EW (transverse).

(ii) *Central Europe.* Of the Central Europe stations, whose EW and NS components approximately or very nearly corresponded to the longitudinal and transverse vibrations, Potsdam and Göttingen show very clearly the following characteristics:—

(*a*) In the 1st Preliminary Tremor, EW motion was much greater than the NS motion.

(*b*) In the 2nd Preliminary Tremor and the 1st and 2nd Phases of the Principal Portion, the EW motion was much smaller than the NS motion.

(*c*) In the 3rd Phase of the Principal Portion, the EW motion was greater than the NS motion.

(*d*) W_2.... EW motion was much greater than NS motion.

Again, the 4 other stations of Quarto-Castello, Leipzig, O'Gyalla, and Ischia,[*] show the following characteristics:—

(*a*) In the 1st Preliminary Tremor, the EW motion was greater than the NS motion.

(*b*) In the 2nd Preliminary Tremor and the 1st and 2nd Phases of the Principal Portion, the EW motion was much smaller than the NS motion.

(*c*) The NS Component motion was, except for Ischia, on the whole greater than the EW component motion.

(*d*) 3rd and 4th Phases of Principal Portion...... At Ischia, the EW motion was much greater than the NS motion.

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[*] The copies of the seismograms obtained at these 4 stations were not long enough to enable me to identify the W_2 motion.

(iii) *Japan.* The seismograms obtained at Tokyo, Osaka and Kobe, whose EW and NS components approximately correspond to the longitudinal and transverse vibrations respectively, show the following characteristics :—

(*a*) In the 1st Preliminary Tremor, the EW motion was greater than the NS motion.

(*b*) In the 2nd Preliminary Tremor and the 1st and 2nd Phases of the Principal Portion, the EW motion was smaller than NS motion.

(*c*) In the 3rd and 4th Phases, Principal Portion, the EW motion was greater than the NS motion.

(*d*) W_2........EW motion was greater than NS motion.

Summary. Although the interference of the proper instrumental oscillations makes it often very difficult to form a correct comparison of the vibration amplitudes between the different seismograms, we may conclude from what was stated above provisionally as follows:—In the preliminary tremor and the 3rd and 4th phases of the principal portion, as well as the principal part of the W_2 motion, the longitudinal vibrations predominate more than the transverse; while in the 2nd preliminary tremor and the 1st and 2nd phases of the principal portion, the transverse vibrations predominate more than the longitudinal.* The difference in the magnitude of motion between the two component wave vibrations seem to depend, in the cases of the 1st and 2nd preliminary tremors, and the 1st and 2nd phases of the principal portion, chiefly on the predominance or comparative absence of slow movements.

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* In this connection, the reader is referred to Dr. Imamura's paper: "Note on the Direction and Magnitude of the vibrations in the Different Phases of the Earthquake Motion.' The *Bulletin*, Vol. I, No. 3.

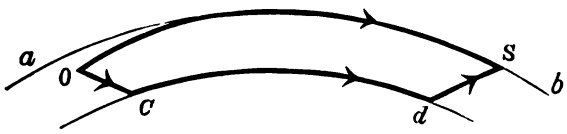
Of the sections later than the 3rd phase of the principal portion, the 8th, or the commencement of the end portion seems to be due to the transverse motion. (See the *Publications*, No. 13.)

163. ***Paths of Earthquake Propagation.*** That the vibrations of the 3rd, and in many cases strongest, phase of the principal portion are propagated along the earth's surface seems to be evident, their transit velocity being the same as that of the ordinary macroseismic or sensible earthquake motion of near origin. It thus seems that the principal energy of the earthquake shock is propagated not through the earth's interior. the observations having shown so far no positive instance of such seismic transmission to places at a considerable distance from the origin of disturbance. In the case of the Kangra earthquake, the furthest station was Tacubaya, whose epicentral arcual distance was a little more than $\frac{1}{3}$ of the whole earth's circumference ; the different velocities for Tacubaya, however, not showing an evidence of the internal direct transmisson. The improbability of the chord hypothesis has already been pointed out in § 118.

As regards the preliminary tremors, I have stated in the *Publications*, No. 5, a supposition that the disturbances with the transit velocity v_1 probably travels parallel to the earth's surface at some constant depth, the formation of the small vibrations in the 1st preliminary tremor being explained as follows :—A small part of the seismic energy communicated in a downward direction at the origin causes some feeble shaking to be propagated towards the earth's interior. Such a disturbance travels with a high velocity of over 10 km/sec., along a layer some depth below the surface, and would constitute a progressive source of stress and give a sort of impetus to the upper layer of the earth's crust in a given region; the latter being consequently thrown into its own proper oscillations of periods P_1, P_2, etc.

The layer here considered may be supposed as marking the limit beyond which, the seismic waves are, on account of some physical properties of the underlying medium, unable to penetrate.* One method of expalaining the discrepancy between the velocities calculated by the "direct method" and the corresponding values calculated by the "difference method" is to suppose the layer in the above hypothesis to be tolerably deep. Dr. Imamura thinks, as results of his studies in this connection, the depth of the layer in question to be several hundred kilometres.‡ Diagrammatically the paths of the vibrations of the 1st preliminary tremor and the 3rd phase of the principal portion would be respectively somewhat like *ocds* and *os* in Fig. 20.

Fig. 20.



ab....Earth's Surface.
cd....Path of 1st Prel. Tremor Vibrations.
o....Eqke Centre.
s....Observing Station.

164. ***Conclusion.*** There are many points to be discussed in connection with the teleseismic motion, which have not been touched upon in the foregoing pages. A comparison of the observations of the Kangra earthquake with those relating to the Assam and Bengal earthquake of 1897 and other large recent earthquakes is reserved for a future occasion. Whether the comparatively low transit velocities of the Kangra earthquake were connected with the continental origin requires further studies.

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* Prof. H. Nagaoka has proposed a theory of the layer, along which the propagation velocity is maximum. See the *Publications*, No. 4.

‡ A. Imamura: "On the Transit velocity of the Earthquake motion originating at a near distance." The *Publications*, No. 18.

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